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Comparative Carbon Storage of Lanzones (*Lansium domesticum*)-fruit tree and Falcata(*Paraserianthes falcataria*)-forest tree based Agroforestry Systems

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ABSTRACT

Two agroforestry systems, a fruit tree-based with lanzones (*Lansium domesticum*) as dominant fruit tree and a forest tree-based with falcata (*Paraserianthes falcataria*) as dominant wood tree, were studied to compare their total carbon stocks in the above ground biomass (upperstorey and understorey), floor litters and soil and to determine any differences of soil organic carbon (SOC) in three soil depths: 0-30, 31-60 and 61-100 cm. Each site representing one agroforestry systems was grouped according to vegetation stand. For each vegetation stand, representative samples were taken from upper storey and under storey above ground biomass, floor litters and soil. Samples were analyzed for carbon content at International Rice Research Institute's (IRRI) Analytical Service Laboratories (ASL), Los Baños, Laguna using Dumas Combustion Method.

The SOC in the soil depths (0-30, 31-60 and 61-100 cm) did not vary significantly in the two agroforestry systems. The above ground upperstorey biomass had the most carbon followed by the carbon stored in the soil, then, above ground understorey biomass and lastly, floor litters. The above ground upperstorey biomass of the fruit tree-based agroforestry system had slightly higher carbon stock at 38.92 tC ha^{-1} compared with the forest tree-based agroforestry system at 34.66 tC ha^{-1} due to the lanzones fruit tress. The 4 - year old falcata-based agroforestry systems had higher annual C sequestration of 14 tC ha^{-1} yr^{-1} while the lanzones-based agroforestry system had 1.8 tC ha^{-1} yr^{-1}. Nevertheless, whatever is the main tree component, agroforestry performs ecological services as in carbon sequestration and at the same time provides financial benefits.

Keywords: carbon stocks; agroforestry systems; carbon density; biomass; soil organic carbon; floor litter

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INTRODUCTION

The ecosystem services of the forests in the hydrologic cycle, soil and biodiversity conservation and carbon dioxide (CO_2) sequestration are well recognized (Sales *et al.*, 2005). The forest ecosystem stores carbon as lignin, humic and non-humic substances and other relatively resistant polymeric carbon compounds which explains why the forests have the biggest long-term potential to sequester atmospheric carbon (IPCC, 1995). The forest carbon is sequestered not only in the harvestable timber, but also in woody debris, wood products and other woody plants and also in the soil (Lasco & Pulhin, 2009). Tropical forests, in particular, account for 26% of global carbon storage in biomass and soils (Dixon *et al.*, 1994, and Grace, 2004).

The importance of forests is well known but the need for lands to grow crops and raise animals and the need for lumber to build human settlements led to widespread and unabated timber harvesting or logging. Continuing population pressure to use more lands for food production had resulted in massive deforestation with several on-site and off-site undesirable consequences. In connection to climate change, the conversion of tropical forests to agricultural lands and the ensuing agricultural practices, jointly, had contributed large amount of greenhouse gases (GHG) in the atmosphere causing global warming (Lal, 2004) Reforestation is the key strategy in lessening the negative impacts of global warming climate change. (Brown, 2008). Under Philippine setting where many people are already doing farming in the uplands, it will be difficult to advice the upland dwellers to plant trees only. As an alternative to pure reforestation, the practical strategy is through agroforestry, or the growing of trees and agricultural crops including animals in the same piece of land, either in some form of spatial mixture or temporal sequence (Nair *et al.*, 2009). As an alternative to natural forest, agroforest conserves the soil and water while the augmented growth of trees and shrubs sequesters carbon (Paustian *et a*l., 2000). In smallholder agroforestry systems of the tropics , an average rate of 1.5 to 3.5 tC $ha^{-1}yr^{-1}$ (Watson *et al.,* 2000) and up to 1.03 to 4.58 tC $ha^{-1}yr^{-1}$ in over 12.5 million hectares of cropped lands (uplands, coconut land, upland rice lands) in the Philippines (Mendoza, 2003) are sequestered .

Global land area for agroforestry was estimated at around 1,300 million hectares in croplands (Watson *et al.,* 2000) while over 895 million hectares in Asia, Africa, and Latin America (Nair *et al.*, 2009). Agroforesatry can help sequester back the terrestrial C emission estimated at 200 to 500 billion tons representing 25% of global carbon stocks (Albrecht & Kandji, 2003).

As a land-use system, in addition to climate change mitigation through carbon sequestration and storage, agroforestry provides numerous *environmental services* (soil structure stabilization, decreases soil erosion, nutrient cycling, increased water infiltration, and biodiversity conservation), and *economic benefits* (increased food production and food security, increased farm income, secure land tenure in developing countries). These features of agroforestry are well recognized by the Philippine government in addressing environmental degradation.

However, the carbon sequestration and storage of agroforestry systems depend on several factors (Albrecht & Kandji, 2003) which include the age, the structure and the way the system is managed, the type of tree species use, the site conditions and the silvicultural treatments applied in the stand (Sales *et al.,* 2005). This suggests that the carbon sequestration rate, or the accumulation rate of carbon in growing vegetation, is generally higher in managed tree plantations and agroforestry systems than in mature intact rain forests (Lasco & Pulhin, 2009).

Carbon sequestration in the ecosystems is measured as the sum of stored carbon in the different carbon pool usually expressed in mass units (tonnes C). Carbon pool is a complex mixture of live and dead organic matter brought about by biotic factors or the above ground carbon plus the organic carbon stored in the soil. This study was conducted to compare the carbon storage capacity of lanzones-fruit tree- and falcata-forest tree-based agroforestry systems in both above ground biomass and the carbon stored in the soil as soil organic carbon, and to find out which of the 2 agroforestry systems is better to promote for adoption among the upland farmers in the Philippines in terms of carbon sequestration and/or in terms of economic benefits.

MATERIALS AND METHODS

Description of the Study Areas

The study was conducted in two agroforestry areas where one was planted with lanzones (*Lansium domesticum*) and coconuts (*Cocos nucifera*) while the other was planted with falcata (*Paraserianthes falcataria*) in association with banana (*Musa spp*) and coconuts. Both areas are located adjacent to each other in order to have fairly the same environmental influences such as soil properties, topography and geophysical characteristics. The site of the study is located within the proposed Calayagon Watershed CBFM area in Purok 9 Barangay Rizal, Buenavista, Agusan del Norte in Caraga Region (Figure 1). With an aggregate area of 1,142.15 hectares, the study site belongs to the Tacub Upland Farmers Association (TUFA) Inc. It lies between 08º 55' North and 125º 23' East. Based on the modified Coronas Classification, the site has type II climate which is described as no dry season with a very pronounced rainfall from November to January with a mean annual precipitation of 1,924.6 mm. The wettest month in 2009 was in November where the total rainfall recorded was 472.1mm. The driest month was in September where rainfall was only 43.1mm (Butuan PAGASA Station, 2009).

The site is relatively flat and located beside the Guijao-an river channel and is being protected by bamboos along the riverbanks. According to Alcasid (1995), the soils in the sites are classified as Inceptisols. These soils are unique soil order where they are essentially intermediate between soils of any other order and soils that have no diagnostic subsurface horizon (Galbraith & Engel, 2006). Inceptisols can be formed in any type of parent material except thick organic deposits. They occur on any slope or landform from floodplains to mountaintops and are found under all vegetation types (Selvaradjon *et al.,* 2005).

Sampling Procedure

Each site representing one agroforestry systems was grouped according to vegetation stand and categorized as poor (plot 1), average (plot 2) and good (plot 3) as shown in Table 1. For lanzones fruit tree-based agroforestry systems, the lanzones tree-counts in each group were as follows: Poor-Less dense contains (49%) 21 trees and below; Average-Medium stocked contains (50-74%) 22-32 trees; Good stocked/densed contains (75%) 33 trees and above. For falcata wood tree-based agroforestry systems, falcata trees in Poor-Less dense contains (49%) 12 trees and below; Average-Medium stocked contains (50-74%) 13-18 trees; Good stocked/densed contains (75%) 19 trees and above.

Three plots (20m × 20m) per vegetation group (poor, average, good) for the 2 agroforestry systems (fruit tree-based with lanzones and a forest tree-based with falcata) were identified. Each of the three 20m × 20m plot (representing one replication) was divided further into 1m × 1m quadrat and from the 400 quadrats, 3 quadrats were randomly selected for collecting understorey biomass, floor litters, and soil samples.

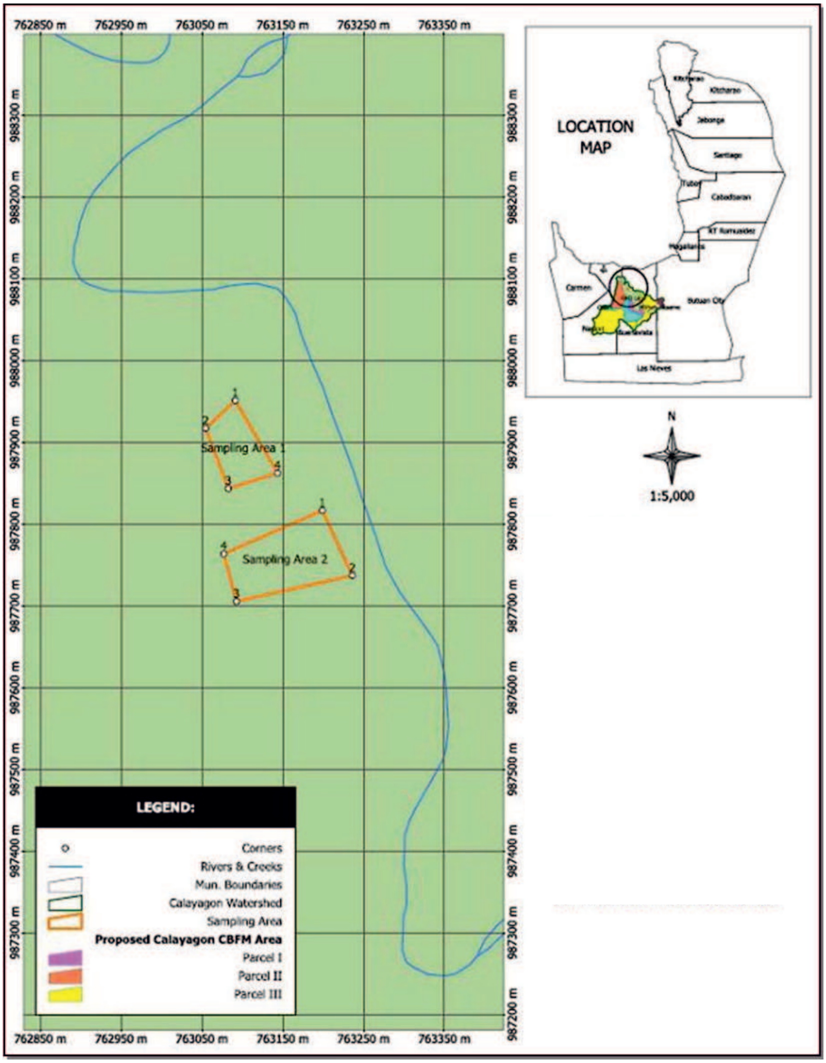

Figure 1. Location map of the research site.

Table 1. Characteristics of the agroforestry areas classified into poor, average, good site stratification criteria.

Characteristics	Poor	Average	Good
For the lanzones trees:			
Density/Stocking	Less dense	Medium stocked	Full stocked/densed
Height of stand and size of crown	Shortest height (<8 m); narrow canopy with few branches	Medium height (8 to 10 m); wide canopy with few branches	Tallest height (>10 m); wide canopy with many healthy branches
Size and appearance of bole	Small DBH (<17 cm); crooked; forking	Medium sized DBH (17 to 20 cm); low first branch	Big DBH (>20 cm); straight bole; high first branch
For the falcata trees:			
Density/Stocking	Less dense	Medium stocked	Full stocked/densed
Height of stand and size of crown	Shortest height (<17m); narrow canopy with few branches	Medium height (17 to 18m); wide canopy with few branches	Tallest height (>18m); wide canopy with many healthy branches
Size and appearance of bole	Small DBH (<20cm); crooked; forking	Medium sized DBH (20 to 28cm); low first branch	Big DBH (>28cm); straight bole; high first branch

Carbon (C) yield estimation

To determine the carbon stocks for the 2 agroforestry systems, above-ground biomass, floor litter, and soil samples were collected. The above-ground biomass has 2 parts: the upperstorey/tree biomass and the understorey and herbaceous vegetation. For the upperstorey/tree biomass, the dominant trees/plants were measured and the following data were recorded: species name, diameter-at-breast-height (DBH) at 1.3 m above the ground, and total height in the 20m × 20m sampling plot. To estimate the carbon (C) yield of the various vegetations, suitable equations were formulated. For falcata, the following equation was formulated to compute for the carbon yield:

$$C_f = (Y_{bf})\ (1\text{-}0.587)\ (0.45) \quad \text{(equation 1.0)}$$

Where: C_f = carbon yield of falcata in tC ha^{-1}

Y_{bf} = fresh biomass yield of falcata (in kg) and estimated as $Y_{bf} = 10\text{^}[-0.9836 + 1.8036*\log(D) + 0.8702*\log10(H)]$, D = DBH in cm and H = tree height in cm (Tandug, 2009)

-0.587 = dry matter content of falcata biomass (Tandug, 2009);

0.45 = carbon content of falcata biomass (Lasco & Pulhin, 2003).

For the carbon yield computation of lanzones and other fruit trees, the following equation was used:

$$C_{ft} = (Y_{ftb})\ (0.45) \qquad \text{(equation 2.0)}$$

Where: C_{ft} = Carbon yield of fruit tree in tC ha^{-1};

Y_{ftb} = Fruit tree biomass = $\exp[-2.4090+0.9522*\ln(D^2HS)]$ (Unruh *et.al.*, 1993), D = DBH in cm , H = Tree height in cm , S = Wood density equivalent to 0.57

For the carbon yield of coconut palms, the biomass equation of Frangi and Lugo (1985) as cited by Brown (1997) was adopted.

$$C_c = (Y_{cfb})\ (1\text{-}0.6)\ (0.45) \qquad \text{(equation 3.0)}$$

Where: C_c = Carbon yield of coconut in tC ha^{-1},

Y_{cfb} = coconut fresh biomass in kg and estimated as $Y_{cfb} = 10.0 + 6.4 * TH$ (Frangi & Lugo,1985), TH = total height in meter,10.0 + 6.4 = Constant ,

1-0.6 = dry matter content of coconut palm (Killmann & Fink, 1996)

Also, the 45 percent carbon content of wood biomass as used by various researchers (Lasco & Pulhin , 2003; Andreae & Merlet, 2001; Chambers *et al.*, 2001; McGroddy *et al.*, 2004) and as cited in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories was adopted.

In order to account the carbon yield of bananas, the equation developed by Armecin and Gabon (2008) was adopted as follows:

$$C_b = (Y_b)\ (1\text{-}0.90)\ (0.642)\ (0.58) \qquad \text{(equation 4.0)}$$

Where: C_b = Carbon yield of banana in tC ha^{-1},

Y_b = Biomass in kg = $[-228.65 + 6.75(X*100)]/1000$ (Armecin & Gabon, 2008) ,

X = pseudostem length , 1-0.90 = dry matter content of pseudo stem ,

0.642 = organic matter content of the biomass ,0.58 = carbon content in organic matter

Since non-destructive sampling was employed in this study, conversions were done to derive the carbon content of bananas. Ninety to ninety-five (90-95%) of chopped banana pseudostem is water and 64.2% of the biomass is organic matter (Simmonds, 1966). To get the carbon content, the organic matter was multiplied by 58% as reported by McConkey *et al.* (1999).

The total carbon (C) of the upperstorey biomass was estimated as follows:

$$\text{Total } C_{upperbio} = C_f + C_{ft} + C_c + C_b \text{ tC ha}^{-1} \qquad \text{(equation 5.0)}$$

Where: C_f = Carbon yield of falcata (equation 1.0), Y_{ft} = Carbon yield of fruit tree (equation 2.0) C_c = Carbon yield of coconut (equation 3.0), Y_b = Carbon yield of banana (equation 4.0)

Understorey and Herbaceous Vegetation

In the randomly selected three sub-sample frames(1m × 1m), all herbaceous and woody vegetations with < 10 cm DBH growing inside the frame were harvested (Lasco *et al.,* 2006). Fresh weights of the samples which were grouped into leaves-twigs, branches and stems-were determined and representative samples were taken for oven-drying. All plant samples were chopped into small pieces and oven-dried at 70°C to a constant weight (Chambers *et al.*, 2001; Feldpausch *et al.*, 2004). When the constant dry weights were obtained, respective weight values of biomass samples were computed to determine their corresponding carbon content based on 43% carbon fraction (Feldpausch *et al.*, 2004).

Floor Litters

Litter samples composed of different dead plant tissues (also known as necromass) were collected and mixed together and took their fresh weights were also taken. Representative samples were taken for oven-drying and laboratory analysis at the International Rice Research Institute's Analytical Service Laboratories, Los Baños, Laguna. To get the total carbon of floor litters samples, the Dumas Combustion method was adopted (Kirsten, 1983).

Soil Organic Carbon

Within each sub-sample plot, soil samples were taken at various depths (0-30, 31-60 and 61-100 cm). The SOC was analyzed in the Regional Soils Laboratory of the Department of Agriculture in Butuan City and the SOC stocks was calculated using the equation below:

$$\text{SOC stocks (tC ha}^{-1}\text{)} = (SV_{ssd})\ (BD)\ (\%SOC/100) \qquad \text{(equation 7.0)}$$

Where: SV_{ssd} = Soil volume at specified soil depth = 10,000 m^2 × specified depth (m)
BD = bulk density (kg/m^3),
%SOC = determined thru laboratory analysis

Total Carbon Estimates per Agroforestry System

To get the total carbon of the two agroforestry systems, the upperstorey and understorey biomass, floor litters and soil were added as follows:

$$\text{Total } C_{area}\ (\text{tC ha}^{-1}) = C_{upperbio} + C_{underbio} + C_{fl} + C_{SOC} \quad \text{(equation 8.0)}$$

Where: $C_{upperbio}$ = Upperstorey biomass carbon
$C_{underbio}$ = Understorey biomass carbon
C_{fl} = Floor litter carbon
C_{SOC} = Soil organic carbon

RESULTS AND DISCUSSION

Total Carbon Stock

On the average, the total carbon stock in the falcata-based agroforestry system and the lanzones-based agroforestry system were 56 tC ha^{-1} and 54 tC ha^{-1} , respectively (Table 2), of the carbon stored in the understorey, floor litter and soil organic carbon were 3 tC ha^{-1}, 8 tC ha^{-1}, and 9 tC ha^{-1}, respectively or a total of 21 tC ha^{-1} (21%). In the lanzones-based agroforestry system, the carbon stocks were 6 tC ha^{-1}, 4 tC ha^{-1}, 6 tC ha^{-1} for the understorey, floor litter and soil organic carbon, respectively or a total of 15.77 tC ha^{-1} or about 15.77% of the total carbon stored at 54.38 tC ha^{-1}. In both agroforestry systems, the total carbon stocks increased from 47.47, 52.91, and 67.02 tC ha^{-1} for the poor, average and good standing plots (Plots 1, 2, 3), respectively, for the falcata-based agroforestry system while total carbon stocks ranged from 43.85, 51.93, and 67.36 tC ha^{-1}, for the poor, average and good standing plots (Plots 1, 2, 3), respectively , in the lanzones-based agroforestry system.

Table 2. Carbon stocks of the various carbon yielding components in the 2 agroforestry systems.

Af System /plot	UPPERSTOREY (tC ha^{-1})	UNDERSTOREY (tC ha^{-1})	LITTERS (tC ha^{-1})	SOIL (tC ha^{-1})	TOTAL (tC ha^{-1})
Lanzones-Based Agroforestry System					
Plot 1 (n=3?)	25.19	9.12	2.91	6.63	43.85
Plot 2	36.72	4.90	3.68	6.63	51.93
Plot 3	53.91	2.97	5.02	5.46	67.36
Mean	38.61	5.66	3.87	6.24	54.38
STD	14.45	3.15	1.07	0.68	11.94
Percentage (%)	70.99	10.41	7.12	11.47	
Falcata-Based Agroforestry System					
Plot 1	29.74	4.78	5.05	7.90	47.47
Plot 2	34.68	3.18	7.08	7.98	52.92
Plot 3	40.22	2.19	12.17	12.54	67.12
Mean	34.88	3.38	8.10	9.47	55.84
STD	5.24	1.31	3.67	2.66	10.14
Percentage (%)	62.47	6.06	14.51	16.97	

NOTE: Age of lanzones trees = 30 years old. Annual C sequestration in lanzones-based =54.38/30= 1.81 tC ha^{-1} yr^{-1}. Age of falcata trees = 4 years old. Annual C sequestration in falcata-based =55.84/4 = 13.96 tC ha^{-1} yr^{-1}

The upperstorey biomass of the fruit tree-based agroforestry system had a carbon stock at 38.92 tC ha^{-1} (71%) while the forest tree-based agroforestry system at 34.66 tC ha^{-1} (62.5 %). The difference was due mainly to the stored carbon in the coconuts and jackfruits biomass at 5.58 tC ha^{-1} and 3.96 tC ha^{-1}, respectively, which accounted for about 24.51% of the upper storey stored carbon. Although there were several bananas in the falcata-based agroforestry system, they did not contribute much to the total carbon yield because bananas (0.07 tC ha^{-1}) contain only 10% dry biomass and there were fewer stored carbon contributed by jackfruits

(2.73 tC ha^{-1}) and coconuts(1.17 tC ha^{-1}). Their combined carbon sequestered was only 3.97 tC ha^{-1} or 11.45% of the total upperstorey carbon stored at 34.65 tC ha^{-1}. While the falcata were planted at 4 × 4m spacing and intercropped with bananas, there were few stands of coconuts and jackfruits based on the actual number of plant count.

The understorey vegetation (mostly woody plants composed of shrubs, herbs, ferns and vines) in lanzones-based agroforestry system were greater, hence, stored carbon was at 5.66 tC ha^{-1}. Because there were canopies of the upperstorey crops, there was enough sunlight that penetrated underneath favoring the growth of shrubs, herbs and ferns. Under falcata-based agroforestry system, the type of vegetation that occupied the spaces underneath was a vine, *Wedelia trilobata,* that suppressed the growth of other plants. Hence, the stored carbon at 3.38 tC ha^{-1} was mainly that of the *Wedelia trilobata,* an invasive, very aggressive and vigorous ground-creeping vine that forms a dense mat wherein its stems form roots into the ground as the plant spreads horizontally. According to Hensley (1997), it can and will overgrow planting areas, low-growing shrubs, other groundcovers, and small items in the bed. It was not known how this weed came to the place and where it originated. Though it was so fast to cover the whole area and suppressed the growth of other plants, it protected the soil from erosion because the area is easily flooded as shown in the higher carbon density of the soil. This type of weed is excellent for erosion control on slopes and banks (Hensley, 1997).

Comparing the 2 dominant species in the 2 agroforestry systems in their capacity to sequester carbon, the falcata trees had higher carbon sequestered at 32.50 tC ha^{-1} while lanzones had 29.38 tC ha^{-1}. There were more lanzones at 675 trees per ha but few survived after 30 years(61 %) while falcata had an average of 525 falcata trees (84 % survival). While their number was smaller, falcata trees had bigger boles/trunks, greater biomass and higher carbon sequestered (Table 2).

On a per year basis, the carbon sequestration potential of fruit tree- and forest tree-based agroforestry systems could be higher than pure forest tree plantation. Agroforestry systems have higher plant density as compared to pure forest tree plantations. The carbon content of above-ground biomass of secondary and old growth forests in our country were estimated at 207.9 tC ha^{-1} and 165-260 tC ha^{-1}, respectively (Lasco & Pulhin, 2003). Lasco and Pulhin (2009) reported that in Mindanao, Philippines, a 100-year old dipterocarp forest had a carbon stock of 119.43 tC ha^{-1} with a mean annual increment (MAI) at 1.19 tC ha^{-1} yr^{-1}. In their study, the falcata gained 8.13 tC ha^{-1} yr^{-1}; Gmelina+cacao agroforestry in Mt. Makiling had total carbon stocks at 113.4 tC ha^{-1}, and Narra+cacao at 84.3 tC ha^{-1} (Lasco & Pulhin ,2009). The differences in values was due to the different species, densities of tree plantations, and age of the species (Lasco & Pulhin, 2009).

A 4-year old falcata plantation in Mindanao, Philippines, accumulated 31.28 tC ha^{-1} (Lasco & Pulhin, 2009). The total carbon stored in 4 year falcata- based agroforestry systems in this study had a mean C stock at 55.84 tC ha^{-1} or about 78.5% higher than the pure stand falcata plantation. The study periods were different and the situations were also different. The higher biomass accumulation of falcata in the current study could be attributed to the even distribution of rainfall ranging from 104.8 cm to 308.0 cm per year in the agroforestry site. In addition, the site is located in a river channel. Water is very important for fast-growing tree species for their sustained photosynthesis and growth. Tandug (2009) reported a mean moisture content of falcata at 58.7% or more than half of its biomass is water, which means that abundant water is necessary for fast growth and development. In terms of nutrition, falcata is a nitrogen-fixing tree species.

Carbon sequestration in annual crop monocultures in the Philippines had been estimated as follows: rice at 3.1 tC ha^{-1}, while sugarcane and banana at 12.5 tC ha^{-1} and 5.7 tC ha^{-1}, respectively (Lasco & Pulhin, 2009). Except for sugarcane, carbon sequestration in annual crops are lower than carbon sequestration in this fast growing tree species like falcata at 8.72 tC ha^{-1} yr^{-1}. In this study, the wood tree falcata-based agroforestry systems had an annual C sequestration of about 13.96 tC ha^{-1} yr^{-1} when the other above ground biomass were included. The lanzones-based agroforestry systems had an annual C sequestration of about 1.81 tC ha^{-1} yr^{-1}. The lanzones had reached maturity which explained their slow growth, hence the low carbon sequestration.

Soil Organic Carbon Stock

The SOC stocks of the different soil depths (0-30, 31-60, and 61-100 cm) (Table 2)were found almost similar, but the SOC of falcata-based agroforestry systems at 9.47 tC ha^{-1} was 51.76% higher than the lanzones-based at 6.24 tC ha^{-1}. The higher carbon content in the soil under the falcata-based agroforestry system than in lanzones-based agroforestry system could be attributed to the kind of ground cover in each area. The lanzones-based agroforestry system understorey vegetation was composed of shrubs and herbs which could not protect the soil from the strong flood water current. The falcata-based which was covered with *Wedelia trilobata* held the topsoil and even the underlying necromass. Hensley (1997) observed that *Wedelia trilobata* is a good ground cover and soil erosion control which enabled the vine to efficiently hold on the soil particle.

Table 3. Carbon yield of upperstorey crop components in the two agroforestry(Af) systems.

Af System/ plot	Lanzones (tC ha^{-1})	Falcata (tC ha^{-1})	Coconut (tC ha^{-1})	Banana (tC ha^{-1})	Jacfruit (tC ha^{-1})	Total (tC ha^{-1})
Lanzones-Based Agroforestry System						
Plot 1	21.20	-	2.89	-	-	24.09
Plot 2	22.67	-	6.42	-	7.62	36.71
Plot 3	44.26	-	5.41	-	4.25	39.71
Mean	22.51	-	5.58	-	3.96	33.5
Percentage (%)	76.09	0.95	12.71	0	10.25	
Falcata-Based Agroforestry System						
Plot 1	-	29.28	0.39	0.07	-	29.74
Plot 2	-	28.64	2.58	0.06	2.73	34.01
Plot 3	-	39.67	0.55	-	-	40.22
Mean	-	32.53	1.17	0.07	2.73	34.66
Percentage	-	93.26	3.36	0.12	7.87	

NOTE: Annual C sequestration of 30-yr old lanzones trees was 0.98 tC ha^{-1} yr^{-1}
Annual C sequestration of 4-yr old falcata trees was 8.13 tC ha^{-1} yr^{-1}

Floor Litter Carbon Stock

Between the 2 agroforestry systems,the lanzones-based agroforestry system had lower floor litter carbon than the falcata-based agroforestry system(Table 2). Litters collected from the falcata-based agroforestry had a mean carbon of 32.5% and from the lanzones-based agroforestry system, 11%.

The difference in the mean carbon content of floor litters in the two agroforestry systems was attributed to the greater floor litter samples obtained in falcata-based agroforestry system. There were more dead plant parts trapped beneath the *Wedelia trilobata* vegetation; hence, more litter samples were collected as compared to the lanzones-based agroforestry system. As pointed out earlier, the creeping nature and dense biomass formed by *Wedelia trilobata* conserved the floor litter which in turn explained the higher SOC inside the falcata-based agroforestry systems.

Another point to consider in studying floor litters is that the bulk of plant litter. The carbon density of floor litter samples gathered from the two agroforestry systems (AFS) differed and it was noted to be higher in the falcata-based AFS which could be attributed to more litter falls that accumulate in this AFS, as explained earlier. In general, however, both agroforestry systems had lower carbon content of floor litters which suggests that rapid decomposition of floor liters is taking place due to the availability of moisture and favorable temperature in a tropical humid environment obtained in the study site. The carbon stored as SOC is the major natural carbon pool in tropical ecosystems (Schnitzer, 1991) .

The 2 agroforestry systems in terms of financial return

The lanzones-based agroforestry system provides yearly income to the farmer when the tree lanzones start bearing fruits about 15-20 years after planting. At optimum fruiting age, a lanzones tree can bear fruit more than 41 kilograms per year (Montoso, 2007). Given that the age of the lanzones that was studied was 30 years old, fruit production was only around 10 kg/tree/year. A hectare of lanzones (675 trees only as 40% died) would yield 6,750 kilograms of fruits. Considering the farm-gate price of the lanzones fruits in the region at Php 25.00 per kg , the farmer may earn more or less Php 168,750.00 annually. This excludes the income derived from coconuts and bananas .

In a tree-based agroforestry system, falcata trees are harvestable for pulp and paper starting from the 8th year which means that falcata as the main agroforestry crop provides income much earlier than lanzones. In both systems, however, the farmer could also have income from the minor crops such as bananas and coconuts. The diameter at breast height (DBH) of the falcata that was studied ranged from 10 to 30 cm or an average of 21 cm at 4 years old. At harvest (4 years after planting), most trees could grow more than 30 cm DBH. Using the equation developed by Tandug (2009), the falcata stand would have an average merchantable volume of 0.48 cubic meters for each tree increasing to 0.96 cubic meters in the 8th year. If 50% of the falcata trees (263 trees/ha) could reach merchantable volume (approximately 252.58 cubic meters) and sold at Php2,000.00, the farmer would then earn a gross income of approximately Php504,960.00 after 8 years or about Php 63,120.00 on an annual basis. (The price of falcata depends on the size of logs, i.e., Php 1,500.00 for <24cm DBH; Php 1,800.00 for 26cm DBH; and Php 2,000 – 2,200.00 for >30cm DBH).

In Caraga Region, there are lots of wood processing plants (WPPs) buying falcata logs to be processed into veneer – a raw material in making plywood. In 2007, Caraga Region was the major producer of falcata logs at 287,258 cubic meters (FMB, 2007) or 78% of the falcata logs supply in the Philippines. These logs come from mixed sources: from plantations to small tree farms and agroforestry. This is being pointed out to indicate that the market for falcata logs is not a problem in the region.

The farmer could earn more in lanzones-based agroforestry (Php 168,750.00 per year) than in falcata-based agroforestry (Php63,120.00 per year), but lanzones fruit could be damaged completely when heavy rains and super typhoons occur. In the recent decades, heavy rains and super typhoons have been frequently occurring in the study site. It has been observed that falcata for logs are not subject to spoilage. Super typhoons may break some falcata branches, but the wood could recover quickly. Broken branches of lanzones require longer time to mature and bear fruits again. There is another option which is not yet being utilized by farmers in the study site. The woods from 8-year old falcata are already good lumber for furniture provided wood treatment is adopted. Furnitures made from wood fetch high prices .

For the falcata-based agroforestry system, the farmer has another option which is to reserve the falcata for carbon trading under the Clean Development Mechanism (CDM) of the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC is working on the CDM which is an arrangement under the Kyoto Protocol allowing industrialized countries with a greenhouse gas reduction commitment to invest in ventures that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries. One of the CDM project activities is tree planting that would serve as carbon sink. It is hoped that in the future, trees planted in agroforestry systems could be considered for carbon trading which may take in the form of Certified Emission Reduction (CER) credits. In 2007-08, the price was 20 Eur per tCO2e (1Eur = Php 55). By 2012, the price decreased to only 1.4 Eur per tCO2e. To motivate farmers to integrate trees in their annual cropping systems (or through agroforestry), it is hoped that they will be compensated well for the C-sequestration in their farm landscape.

CONCLUSION

Carbon sequestration in a fruit tree-based agroforesry system with lanzones as the dominant crop mixed with coconuts and bananas was lower compared to the forest tree-based agroforestry system with falcata as the dominant crop intercropped with coconuts and bananas agroforestry systems. Falcata, a leguminous tree, had a fast growth and high biomass accumulation due to the even distribution of rainfall in a type 2 climate and abundant water supply in the site, being near a river channel. The two agroforestry systems , had comparable total carbon sequestered.

Above-ground biomass (upper storey vegetation) still had the most carbon followed by the carbon stored in the soil then, understorey vegetation and lastly, floor litter . The low carbon stored in the floor litters of fruit tree-based agroforestry systems were due to the topography and geographical location of the area wherein the yearly occurrence of floods led to run-off carrying most of the litterfall. The dominant understorey vegetation, *Wedelia trilobata,* in the falcata-based system held more floor litters beneath resulting to higher carbon in both the litter and soil samples. Soil organic carbon was significantly higher in the wood tree-based agroforestry systems.

Whatever agroforestry system the farmer adopts, agroforestry has the capacity to perform ecological services as in carbon sequestration and, at the same, time provide financial benefits.

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REFERENCES

ALBRECHT, A. and S.T. KANDDJI . 2003. Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystems and Environment* **99** :15–27.

ALCASID, G.N. Jr. 1995. General Soil Map of the Philippines. Department of Agriculture. Bureau of Soils and Water Management. Sheet 3.

ANDRAE, M.O and P. MERLET. 2001. Emission of trace gases and aerosols from biomass burning. *Global Biogeochemical Cycles* **15**: 955-966.

ARMECIN ,R.B. and F.M. GABON. 2008. Biomass, organic carbon and mineral matter contents of abaca *(Musa textilis Nee)* at different stages of growth. *Industrial Crops and Products* **28:** 340–345.

BERG, B , and C. McLAUGHERTY. 2008. *Plant litter: decomposition, humus formation, carbon sequestration.* Second Edition. Springer-Verlag Berlin Heidelberg, GERMANY

BROWN,L.R.2008. *Planting Trees to Sequester Carbon p.165* In PLAN B 3.0.Mobilizing to Save Civilization Earth Policy Institute New York London W W/ Norton & Company.

BROWN, S. 1997. *Estimating biomass of tropical forest: A primer.* FAO Forestry Paper No. 134. Food and Agriculture Organization, Rome.

CHAMBERS, J.Q, SCHIMEL, J.P. and A.D. NOBRE. 2001. Respiration from coarse wood litter in central Amazon forests. *Biogeochemistry* **52:** 115–131.

CHAMBERS, J.Q, DOS SANTOS, J., RIBERIO, R.J. and N. HIGUCHI. 2001. Tree damage, allometric relationships, and above-ground net primary production in a tropical forest. *Forest Ecology and Management* **152:** 73-84.

CHINA TIMES. 2012. *China's carbon traders brace for 'Post-Kyoto Protocol' era.* http://www.wantchinatimes.com/news-subclass-cnt.aspx?id=20121018000039&cid=1505. Accessed Feb.19,2013

FELDPAUSCH, T.R,. RONDON, M.A., FERNANDES, E.C.M., RIHA, S.J . and E. WANDELLI 2004. Carbon and nutrient accumulation in secondary forests regenerating on pastures in Central Amazonia. *Ecological Applications*, **14(4)** Supplement, pp. S164–S176.

GALBRAITH, J.M. and R.J. ENGEL. 2006. *Inceptisols.* In: *Encyclopedia of Soil Science*: 2nd ed. Taylor and Francis pp: 849-853.

HENSLEY, D. 1997. *Ornamentals and flowers*. Cooperative Extension Service, College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa.

INTERGOVERNMENTAL PANEL FOR CLIMATE CHANGE. 2006. *IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme,

KILLMANN W and D. FINK. 1996. *Coconut palm stem processing: technical handbook*. Protrade: Dept. Furniture and Wooden Products Deutsche Gesellschaftfür Technische Zusammenarbeit (GTZ) GmbH, Bonn.

KIRSTEN, W. 1983. *Organic Elemental Analysis: Ultramicro, Micro, and Trace Methods.* Academic Press/Harcourt Brace Jovanovich, New York.

LAL, R.2004.Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science*, **304** :1623–27.

LASCO, R.D., MACDICKEN, K.G., PULHIN, F.B., GUILLERMO, I.Q., SALE, R.F. and R.V.O. CRUZ. 2006. Carbon stocks assessment of a selectively logged dipterocarp forest and wood processing mill in the Philippines. *Journal of Tropical Forest Science* **18(4)**: 212–221.

LASCO, R.D. and F.B. PULHIN . 2009. Carbon budgets of forest ecosystems in the Philippines. *Journal of Environmental Science and Management* **12 (1)**: 1-13.

LASCO, R.D. and F.B. PULHIN. 2003. Philippine forest ecosystems and climate change: Carbon stocks, rate of sequestration and the Kyoto Protocol. *Annals of Tropical Research* **25(2)**: 37-51.

LASCO, R.D. and F.B. PULHIN. 1998. Philippine Forestry and Carbon Dioxide (CO2) Sequestration: Opportunities for Mitigating Climate Change. Environmental Forestry program, College of Forestry, UP Los Baños, 4031 College, Laguna, Philippines

MCCONKEY, B., LIANG, B., LINDWALL,W. and G. PADBURRY. 1999. *The Soil Organic Carbon Story. Agriculture and Agri-Food Canada,* Semiarid Prairie Agricultural Research Centre, Swift Current, SK, S9H 3X2.

MCGRODDY, M.E., T. DAUFRESNE and L.O. HEDIN. 2004. Scaling of C:N:P stoichiometry in forests worldwide: Implications of terrestrial Redfield-type ratios. *Ecology* **85:** 2390-2401.

MENDOZA, T.C. 2003. CO_2-Greenhouse gas reducing potentials of some ecological agricultural practices in the Philippines landscape. *Philippine Journal of Crop Science 2001,* **26(3)**: 31-44

MOTTLE, B.J. 2007. *Selected Methods of Soil Analysis. Earth Science Program.* University of Calgary, Canada, (Unpublished Laboratory Manual).

NAIR, P.K.R., KUMAR, B.M., and V.D. NAIR. 2009. Agroforestry as a strategy for carbon sequestration. *Journal on Plant Nutrition Soil Science* **172,** 10–23.

PAUSTIAN, K., SIX,J., ELLIOTT, E.T. and H.W. HUNT. 2000. Management options for reducing CO2 emissions from agricultural soils. *Biogeochemistry* **48**, 147–163.

SALES, R.F., LASCO, R.D. and R.N. BANATICLA. 2005. *Carbon storage and sequestration potential of smallholder tree farms on Leyte Island, the Philippines*. ACIAR Smallholder Forestry Project - Redevelopment of a Timber Industry Following Extensive Land Clearing: Proceedings from the End-of-Project Workshop. pp 129-141.

SATHAYE, J.A. and N.H. RAVINDRANATH. 1998. Climate change mitigation in the energy and forestry sectors of developing countries, *Ann. Rev. Energy Environ*, **23:** 387-437

SCHNITZER, M. 1991. *Soil organic matter — the next 75 years*, Soil Sci., 151: 41–58, as cited by Lal, Rattan. 2002. Chapter 3: Why carbon sequestration in agricultural soils. Agricultural practices and policies for carbon sequestration in soil. Lewis Publishers (CRC Press Company) Washington, DC.

SCHUMACHER, B.A. 2002. *Methods for the determination of total organic carbon (TOC) in soils and sediments*. United States Environmental Protection Agency, Environmental Sciences Division, National Exposure Research Laboratory.

SELVARADJON, S.K., MONTANARELLA, L. , SPAARGAREN, O. and D. DENT. 2005. *European Digital Archive of Soil Maps (EuDASM).* Soil Maps of Asia DVD-ROM version 21823 EN. Office of the Official Publications of the European Communities, Luxembourg.

SIMMONDS, N.W. 1966. *Bananas,* second edition. Longman Group Ltd., 5 Bentinck St., London.

TANDUG, L.M. 2009. *Biomass and carbon sequestration of forest plantation species in the Philippines*. Terminal Report. Ecosystems Research and Development Bureau, College, Los Baños, Laguna.