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Carbon stock assessment of three selected agroforestry systems in Bukidnon, Philippines

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Abstract. Climate change, caused by global warming, is a phenomenon partly resulting from abundance of carbon dioxide in the atmosphere. It is the most pressing environmental problem of the world today. It persists, and it cannot be stopped. Rather, it can be mitigated. Agroforestry systems as land use can reduce the atmospheric concentration of carbon dioxide. This study therefore aimed to generate data on the carbon stocks of three selected agroforestry systems located within the Province of Bukidnon. The methodologies used include measurement of trees at diameter breast height (dbh) and sampling of herbaceous vegetation, litter, and soil for carbon content determination and farmer interview. Results showed that carbon accumulation of agroforestry systems goes along with the following order: taungya agroforestry system (174 MgC ha^{-1}) > mixed multistorey system (162 MgC ha^{-1}) > falcata-coffee multistorey system (92 MgC ha^{-1}). Carbon was stored in the various pools in the following order of magnitude: soil (77-92%) > trees (7-22%) > herbaceous vegetation and litter (1%). Compared with natural forests, these selected agroforestry systems represents 23-44% of the total carbon stock. Policy programs promoting the establishment of agroforestry systems in idle lands in Bukidnon should be considered.

Key Words: climate change, agroforestry, carbon stock, multistorey system, taungya system.

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Introduction

The recent weather abnormalities experienced in the country and around the world are indications of a changing climate. Series of storms and typhoons entering the country become more frequent, stronger and disastrous like the recent tropical storm Sendong (Washi) that claimed 1 257 lives, destroyed 1.4 billion worth of infrastructures and agricultural crops, and left the cities of Iligan and Cagayan de Oro in devastation (NDRRMC 2012). The situation is most likely to worsen as the Philippines also ranked third in the world and first in Asia in the list of most vulnerable countries to climate change (UNU-EHS 2011).

Climate change, caused by global warming, is a phenomenon partly resulting from the abundance of greenhouse gases (GHG) in the atmosphere. These greenhouse gases, especially carbon dioxide which is the most abundant, traps surface heat in the atmosphere and prevent them from being released in space. This causes the increase in global temperature which also causes the melting of ice glaciers and rising of sea levels and leads to a significant change in the world’s climatic pattern (IPCC 2007; Lasco *et al* 2006).

Forest ecosystems have the largest potential to sequester carbon. Shively (2003) reported that the Philippines rank seventh among the tropical countries in ability to sequester carbon. Ideally, forests are carbon sinks but because of deforestation, they are currently sources of carbon dioxide. Forest ecosystems are also converted into plantation or croplands by slash and burn because of food production. With the conversion of forest into agricultural land, it has become a source of greenhouse gas. According to Merilo (2001) the agriculture sector in the Philippines contributes about 33% of the total greenhouse gas emission locally.

Land-use management such as agroforestry systems or the combination of production of trees with agricultural crops plays a very important role in climate change mitigation by absorbing excess carbon dioxide which is used in the process of photosynthesis by the trees. Carbon is stored in tree biomass and in soil that helps protect natural carbon sinks through the improvement of land productivity and the provision of forest products on agricultural lands (Albrecht & Kandji 2003).

Despite widespread recognition of agroforestry for carbon storage there is still lack of quantitative data on specific systems and their contribution to climate change mitigation. Currently, there are no actual baseline measurements of carbon stocks of agroforestry systems conducted in Bukidnon yet. The results of this study are expected to add to the body of knowledge on the potential of agroforestry systems to store carbon and provide useful information for the national inventory of sinks as mandated to the committed parties including the Philippines in the United Nations Framework Convention on Climate Change (UNFCCC).

This study was conducted to determine and compare the carbon stock capacity of three different agroforestry systems in

Bukidnon and to identify what type of agroforestry system can store more carbon. Specifically, to (1) measure the aboveground biomass accumulation of selected agroforestry systems; (2) determine the amount of carbon stored in agroforestry systems; and (3) recommend policy changes and programs to strengthen the use of agroforestry systems in climate change mitigation.

Materials and Methods

Location and description of the study areas

The study was conducted in the municipalities of Lantapan and Maramag, both of which are located within the Province of Bukidnon. It is located 7° 21' to 8° 35' North latitude and 124° 03' to 125° 16' East longitude. Bukidnon is bounded on the north and northeast by Misamis Oriental, on the East by Agusan Province, on the south and southeast by Davao Province, and on the west and southwest by Lanao and Davao Provinces. The climatic condition of Bukidnon is relatively cool and moist throughout the year. Lantapan falls under Type III of the Modified Corona's Classification, characterized by a short dry season lasting from one to three months and with no pronounced maximum rain period while Maramag falls under Type IV or no very pronounced maximum rain period and no dry seasons. The three selected agroforestry systems studied were as follows: a mixed multistorey system inside the Binahon Agroforestry Farm in Songco, Lantapan, Bukidnon, a taungya agroforestry system in Central Mindanao University (CMU), Musuan, Maramag, Bukidnon, and a falcata-cacao multistorey system in Kasagayan, Panalsalan, Maramag, Bukidnon.

Data Collection

Plot establishment and measurement

The plot establishment and measurement on carbon stocks were conducted using the methods described by MacDicken (1997) and field tested by Delaney (1999) which have been applied in carbon related studies in the Philippines.

At each site, the perimeter of the agroforestry farm was measured using a measuring tape. A sketch map of the farm's agroforestry plantings was prepared where the GPS coordinates of each corner were recorded. From the southeast corner, a measurement one-half the length of the plot was taken. This point was called the turn point (TP). At the TP, a 90° turn towards the plot interior was made and a distance of one-half the width of the plot was measured. The location was called the plot reference point (RP). The GPS coordinates of the RP were recorded. At a bearing of 45° NE from the RP, a distance 80% between the RP and NE corner was measured and established as subplot 1 (Delaney 1999). Subplot 2 was established opposite subplot 1. Subplots were laid out perpendicular to the longest borders, along a line bisecting the RP. The selected farms sampled were small in size (<0.25 ha), so only two subplots per farm were established as recommended by Delaney & Roshetko (1999) in the field testing of the sample protocol.

Collection of samples and computations

Trees and other woody vegetation

Due to practical concerns, destructive sampling is not recommended for large trees. Instead, the biomass is estimated through the use of allometric equations typically relating tree diameter to biomass. The biomass value is then used to calculate the carbon in trees.

All trees with a circumference or diameter at breast height at 1.3 meters (dbh) > 5cm that fall within the plot were measured using measuring tape and later converted to its diameter equivalent using the equation: Diameter (cm) = circumference (cm)/π. Species name was recorded. Tree biomass was calculated using the allometric equation from Brown (1997):

$$Y\ (kg) = \exp\{-2.134 + 2.53 * \ln * D\}$$

Where: exp {...} = "raised to the power of"
ln = "natural log of (...)"
Y = biomass per tree in kg
D = diameter at breast height (1.3m) in cm

Brown's equation is a generic biomass regression based on 170 trees of many species that were destructively sampled in the moist forest zone of three tropical regions which have been used in local studies to determine indirectly the biomass and carbon storage of forest ecosystems However, the use of these generic equations was found to overestimate the actual biomass of trees (Ketterings *et al* 2001; van Noordwijk *et al* 2002) which shows the need to develop species-specific and site-specific equations that yield more reliable estimates of the characteristics of species and conditions of specific locations in the Philippines.

Banaticla *et al* (2007) developed a generic power fit biomass regression equation using existing data from studies involving destructive sampling for biomass determination of trees conducted in several localities in the Philippines. The following general equation was derived using a non-linear estimation procedure by fitting the pooled biomass data to the power function with potential wider applicability:

$$Y = 0.342\ D^{2.073}$$

Where: Y = biomass of the tree
D = diameter at breast height

Brown and Banaticla equations were used as high and low estimates for the tree biomass in this study. Tree biomass density and carbon stored was calculated using the following formula:

Tree biomass density =
Tree biomass (Mg)/Sample area in hectare
C stored ($MgC\ ha^{-1}$) = Tree biomass density * C content

A default value of 45% was used to determine the carbon stored in tree biomass, which is an average carbon content of wood samples collected from secondary forests from several locations in the Philippines (Lasco & Pulhin 2000).

Banaticla and Brown estimates were compared using t-test. Statistical analysis was done using the software Statistical Package for Social Studies (SPSS) version 10.

Table 1. Plant species found in three agroforestry systems in Bukidnon

Common Name	Scientific Name	Family Name
Mixed multistorey system		
Mahogany	*Swietenia macrophylla*	Meliaceae
Tree fern	*Cyathea* sp.	Cyatheaceae
Rattan	*Calamus* sp.	Arecaceae
Marang	*Artocarpus odoratissimus*	Moraceae
Malaruhat	*Eugenia elliptifolia*	Myrtaceae
Eucalyptus	*Eucalyptus robusta*	Myrtaceae
Balete	*Ficus balete*	Moraceae
Narra	*Pterocarpus indicus*	Fabaceae
Mangium	*Acacia mangium*	Fabaceae
African Tulip	*Spathodea campanulata*	Bignoniaceae
Hindang	*Myrica* sp.	Myriaceae
Gold tree/Primavera	*Tabebuia donnell-smithii*	Bignoniaceae
Peanut tree	*Sterculia quadrifida*	Malvaceae
Black wattle	*Acacia mearnsii*	Fabaceae
Langka/Nangka	*Artocarpus heterophyllus*	Moraceae
Lanzones	*Lansium domesticum*	Meliaceae
Hauili	*Ficus septica*	Moraceae
Tibig	*Ficus nota*	Moraceae
Durian	*Durio zibethinus*	Bombacaceae
Dapdap/Ani-i	*Erythrinia fusca*	Fabaceae
Bayok	*Pterospermum diversifolium*	Sterculiaceae
Abaca	*Musa textilis*	Musaceae
White Lauan	*Shorea contorta*	Dipterocarpaceae
Guava	*Psidium guajava*	Myrtaceae
Taungya agroforestry system		
Gmelina	*Gmelina arborea*	Verbenaceae
Anabiong/Hanagdong	*Trema orientalis*	Ulmaceae
Lutya/Karlang	*Dioscorea* sp.	Dioscoreaceae
Gabi	*Colocasia esculenta*	Araceae
Luy-a/Ginger	*Zingiber officinalis*	Zingiberaceae
Cassava	*Manihot esculenta*	Euphorbiaceae
Camote	*Ipomea batatas*	Convolvulaceae
Papaya	*Carica papaya*	Caricaceae
Falcata-coffee multistorey system		
Falcata	*Paraserianthes falcataria*	Mimosaceae
Coffee	*Coffea arabica*	Rubiaceae
Cacao	*Theobroma cacao*	Streculiaceae
Mangga	*Mangifera indica*	Anacardiaceae
Rambutan	*Nephelium lappaceum*	Sapindaceae
Pomelo	*Citrus maxima*	Rutaceae

Herbaceous vegetation and litter layer

Herbaceous vegetation and litter layer samples were collected at the four cardinal directions N, E, S, and W in each plot at a distance of 1m from the outside boundary of the subplot. At these four points, herbaceous material (<5cm diameter) and litter layer was sampled using a circular aluminum sample ring with a diameter of 0.6 m. Each of the herbaceous material and litter samples were weighed using a digital scale and recorded. The samples were mixed well and a subsample of 300g each was taken for moisture content determination.

The samples collected were subjected to air and oven drying. Oven drying was set at 65-70 ºC and observed for at least 48 hours or until the samples reached their stable weight. Oven-dry weights of subsamples were determined to compute for the total dry weights using the formula (Hairiah *et al* 2001):

$$\text{Total dry weight (kg m}^{-2}\text{)} = \frac{\text{Total fresh weight (kg) * subsample dry weight (g)}}{\text{Subsample fresh weight (g) * sample area (m}^2\text{)}}$$

A small sample (2 grams) of each one of the herbaceous vegetation and litter layer was analyzed for carbon content determination at the International Rice Research Institute Analytical Service Laboratory (IRRI-ASL) using the ROBOPREP C-N Biological Sample Converter. Carbon storage in herbaceous vegetation and litter layer was computed using the formula (Lasco *et al* 2006):

$$\text{C stored (MgC ha}^{-1}\text{)} = \text{Total dry weight * C content}$$

Soils

The same aluminum sample ring plot used for herbaceous vegetation and litter was used for soil sampling. Soil samples were taken from each of the sample ring at 0-30 cm depth. The soils were sieved through a 5-mm mesh screen and mixed to a uniform color and consistency then a subsample of 500g was taken for carbon analysis. Soil samples per plot were taken to the College of Agriculture Analytical Service Laboratory of the Central Mindanao University for chemical analysis for Soil Organic Carbon (SOC) using Walkley-Black method (MacDicken 1997).

In one of the four subplots, an undisturbed soil was taken through core sampling to determine bulk density (MacDicken 1997) with an aluminum cylinder with diameter of 5.3 cm and length of 10 cm. Soil samples were initially air-dried and oven dried at 105-110°C for at least 24 hours or until stable weight. Bulk density of the soil was determined through oven drying. To calculate weight of SOC per hectare, the following formula was used (Patricio & Tulod 2010):

$$\text{Carbon density (Mg ha}^{-1}\text{)} = \text{weight of soil * \%SOC}$$

$$\text{Where: Weight of soil (mg)} = \text{bulk density * volume of 1 hectare}$$

$$\text{Bulk density (g/cc)} = \text{Oven-dried weight of soil / Volume of canister}$$

$$\text{Volume of canister} = \pi r^2 h$$

$$\text{Volume of one ha} = 100\text{m} * 100\text{m} * 0.30\text{m}$$

Table 2. Tree biomass density (Mg ha^{-1}) estimates for Banaticla and Brown equations

Agroforestry system	Tree biomass density (Mg ha^{-1})			
	Banaticla	Brown	% difference	Mean
Mixed multistorey system	67.43	88.82	24.08	78.13
Taungya agroforestry system	20.91	35.92	41.79	28.42
Falcata-coffee multistorey system	13.39	17.16	21.97	15.28

Results and Discussion

Plant species composing the tree and crop component in three agroforestry systems were represented by a mixture of timber trees (*Swietenia macrophylla, Eucalyptus robusta, Pterocarpus indicus, Acacia mangium, Shorea contorta, Gmelina arborea, Paraserianthes falcataria, Coffea arabica*), fruit trees (*Artocarpus odoratissimus, Durio zibethinus, Psidium guajava*), shrubs (*Calamus* sp.), and root crops (*Dioscorea* sp., *Colocasia esculenta, Manihot esculenta*). The mixed multistorey system was the most diverse with 24 plant species (Table 1).

Tree biomass density of agroforestry systems

The tree biomass density of agroforestry systems is shown in Table 2. The mixed multistorey system (67-89 Mg ha^{-1}) is almost the same with that of a mixed species land use in Pantabangan-Carranglan watershed with a biomass density of 45-87 Mg ha^{-1} (Lasco *et al* 2005).

For the taungya agroforestry system with 3-5 year-old *G. arborea* as the dominant tree component, the tree biomass density amounted to 21-36 Mg ha^{-1}. This is lower compared with that of the same age of *G. arborea* stands in Leyte with tree biomass density of 36-81 MgC ha^{-1} (Sales *et al* 2004) but higher than a 6-year old pure *Gmelina* plantation (8-17 Mg ha^{-1}) in Nueva Ecija (Lasco & Pulhin 2000).

The falcata-coffee multistorey system had the lowest biomass density among the three agroforestry systems that amounted to 14-17 Mg ha^{-1} for a 5-year old *P. falcataria* trees. This is very low compared with the same 5-year old *P. falcataria* plantation in Mindanao with biomass density 76 Mg ha^{-1} (Lasco & Pulhin 2000). The relatively low biomass density values obtained from this study can be attributed to the small sizes of *P. falcataria* trees. It was noted that the Brown equation had 22-42% higher tree biomass density estimate compared to Banaticla's power fit equation. However, t-test results showed that there was no significant difference in the tree biomass density estimates between Banaticla and Brown equations. Thus, a mean value of the both equation was used to represent the tree biomass density estimate of the agroforestry systems studied.

Table 3. Aboveground biomass density (Mg ha^{-1}) of three selected agroforestry systems

Agroforestry system	Biomass density (Mg ha^{-1})			
	Trees	Herbaceous vegetation	Litter	Total
Mixed multistorey system	78.13* (94%)	0.16 (<1%)	4.5 (5%)	82.79
Taungya agroforestry system	28.42* (91%)	0.98 (3%)	1.89 (6%)	31.29
Falcata-coffee multistorey system	15.28* (85%)	2.29 (13%)	0.42 (2%)	17.99

*Mean value between Banaticla *et al* (2007) and Brown (1997) equations as low and high estimates. Shown in parentheses are the percentage compositions of the different carbon pools.

Table 4. Mean percent carbon of different pools of three selected agroforestry systems

Agroforestry System	Carbon Content (%)			
	Trees	Herbaceous vegetation	Litter	Soils
Mixed multistorey system	45*	37.13	44.68	4.62
Taungya agroforestry system	45*	40.5	43.24	4.32
Falcata-coffee multistorey system	45*	26.51	34.63	2.42

*from Lasco & Pulhin (2000)

Aboveground biomass density of agroforestry systems

Table 3 shows the aboveground biomass density of agroforestry systems. For mixed multistorey system, the aboveground biomass amounted 83 Mg ha^{-1} followed by the taungya agroforestry system with 31 Mg ha^{-1} and lastly, the falcata-coffee multistorey system with 18 Mg ha^{-1}.

It is noted that most (85-94%) of the aboveground biomass is stored in trees. This is consistent with findings from other studies where more than 90% of biomass is commonly found in bigger trees (Lasco *et al* 2005). This was followed by litter with 2-6% and herbaceous vegetation that accounts only to <1-13% of the total aboveground biomass.

Carbon content of different carbon pools

The IPCC (1996) set the default value for carbon content at 50% of the biomass in trees. However, Lasco & Pulhin (2000) conducted a study on the carbon content of wood samples collected from secondary forests from several locations in the Philippines and reported that for Philippine biomass, a default value of 45% could be used in determining carbon stock in trees (Table 4).

The carbon content of herbaceous vegetation for the mixed multistorey system and falcata-coffee multistorey system amounted to 37% and 27% respectively, both of which are lower than the commonly used default value of 50% in the greenhouse gas inventories (Brown *et al* 1996) while the taungya agroforestry system is closer to the default value with carbon content of 40.5%.

For litter layer, the carbon content for mixed multistorey system amounted to 45% while 43% for taungya agroforestry system, both of which are closer to the 50% default value while the carbon content for falcata-coffee multistorey system is 35% which is far from the default value.

Soil organic carbon (SOC) from three agroforestry sites ranged from 2-5%.

Carbon stocks of agroforestry systems

The main portion of the aboveground total carbon stock was from trees equivalent to 7-22% (Table 5). It was followed by litter and herbaceous vegetation with 1% and <1% respectively. Total biomass constitutes 8-23% of the total carbon stored which includes trees, herbaceous vegetation and litter from the three agroforestry systems.

Total soil density constitutes 77-92% of the total carbon density. It is higher than that of a smallholder tree farm in Leyte with almost 60% of the total carbon stock was found in soil (Sales *et al* 2004). Soil is a significant carbon pool because it has the longest residence time of carbon among organic carbon pools (Lugo & Brown 1993). It is therefore important to adopt practices that conserve soil organic matter such as minimum tillage and soil erosion control measures (Lasco *et al* 2001).

The total carbon stock for the mixed multistorey system was 162 MgC ha^{-1}. This is almost the same with that of a second-growth forest in the General Nakar side of the Kaliwa Watershed with carbon stock of 151 MgC ha^{-1} (Lasco *et al* 2007). For the taungya agroforestry system, total carbon stock amounted to 174 MgC ha^{-1}. This is almost the same as that of a Gmelina-cacao multistorey system in Makiling Forest Reserve with 185 MgC ha^{-1} (Lasco *et al* 2001) but lower than that of a pure Gmelina plantation (294 MgC ha^{-1}) in Leyte (Lasco *et al* 2000). Carbon stock for the falcata-coffee multistorey system amounted to 92 MgC ha^{-1} which is the same as that of a computed value of a 4-year old *P. falcataria* pure stands in Manupali watershed in Bukidnon using Uriarte and Pinol's model equation (Shively *et al* 2004). Sales *et al* (2004) reported that fast growing species such as Falcataria and Gmelina can store less carbon than slow-growing species due to their differences in wood density and rotation age. They accumulate more biomass and carbon than slow-growing species for the same period of time. However, fast-growing species typically have lower wood density and thus contain less carbon than wood of slow-growing species (Lasco & Pulhin 2009). Carbon stock and carbon accumulation rates are dependent on the age of plants, plant density, soil fertility of the site, rainfall, and other factors (Brakas & Aune 2011). Old stands will have high carbon stocks, but low carbon accumulation rates since they have reached maturity while young plantations will have low carbon stocks, but higher accumulation rates since the plantation will be in an active growth phase.

Table 5. Carbon stored from three agroforestry systems in different carbon pools

Carbon stocks (MgC ha^{-1})	Agroforestry systems		
	Mixed multistorey system	Taungya agroforestry system	Falcata-coffee multistorey system
Trees	35.16* (22%)	12.79* (7%)	6.88* (7%)
Herbaceous vegetation	0.06 (<1%)	0.40 (<1%)	0.61 (<1%)
Litter	2.01 (1%)	0.82 (<1%)	0.15 (<1%)
Aboveground total	37.23 (23%)	14.01 (8%)	7.64 (8%)
Soil	124.29 (77%)	160.42 (92%)	84.69 (92%)
Total	161.52	174.43	92.33
% Natural forest	41%	44%	23%

*Mean value between low and high estimates of Banaticla (2007) and Brown (1997) equations. Shown in parentheses are the percentage compositions of the different carbon pools.

Carbon was stored in the various pools in the following order of magnitude with percentage composition: soils (77-92%) > trees (7-22%) > litter and herbaceous vegetation (1%). This is the same order of magnitude of carbon pools as that of a multistorey system inside Makiling Forest Reserve in Los Baños, Laguna (Lasco *et al* 2001).
Compared with natural forests, these selected agroforestry systems represent 23-44% of natural forests with carbon density of 393 MgC ha-1 (Lasco *et al* 2000). This is higher compared with the findings of other studies that agroforestry farms are 4-27% lower than an undisturbed forest (Lasco 2002).
Similarly, the total carbon stored in the three agroforestry system is comparable with the carbon storage of agrosilvicultural agroforestry system in the humid tropical ecoregion of Southeast Asia, ranging from 12-228 MgC ha^{-1} with a median value of 95 MgC ha^{-1} (Albrecht & Kandji 2003).

Conclusions

The agroforestry systems sampled in this study include mixed multistorey system, taungya agroforestry system, and falcata-coffee multistorey system. These agroforestry systems were selected based on criteria set and sampling method used. Plant species which consist of timber trees, fruit trees, shrubs, and root crops were found in these agroforestry systems.
Results obtained from this study indicate that these agroforestry systems have the capacity to store carbon in trees, herbaceous vegetation, litter, and soil. The largest amount of carbon was stored in the soil component indicating the need to implement soil management practices in the area to preserve the existing carbon stock.
The mixed multistorey system had the greatest carbon storing potential among the three types of agroforestry system because of its good soil condition which is conducive for plant growth. This type of agroforestry system can store more carbon in the biomass and soil and produces multiple products beneficial to the farmer.
Agroforestry systems can store 92 MgC ha^{-1} to 174 MgC ha^{-1} of carbon therefore, policy programs promoting the establishment of agroforestry systems in idle lands in Bukidnon should be considered.

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