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Carbon Sequestration by Large Leaf Mahogany (*Swietenia macrophylla* King.) Plantation in Mount Makiling Forest Reserve, Philippines: A Decade After

ABSTRACT

The study on monitoring carbon accumulation and sequestration potential of Large Leaf Mahogany (Swietenia macrophylla King.) plantation in Mount Makiling Forest Reserve was a continuation of the same study conducted in 2000. It aimed to look into the sequestration rate of the plantation after a 10-year period. The study measured the biomass, C and CO_2 stored in the aboveground, ground and belowground biomass. It also quantified the rate of C captured with the 2000 study as baseline data. The latest study showed that the plantation has a total biomass production of 1,120 Mg ha^{-1} which is equivalent to 542 Mg ha^{-1} of C and 1,989 Mg ha^{-1} of CO_2. Within a 10-year period, it registered a biomass buildup of 43 Mg ha^{-1} yr^{-1} and sequestered carbon at 22 Mg ha^{-1} yr^{-1} and 81 Mg ha^{-1} yr^{-1} of CO_2. Its carbon storing capacity surpasses that of an old growth forest, natural stand and other types of vegetation. It can be concluded that the potential of forest plantation to sequester carbon can be maximized given a good-site condition, appropriate silvicultural practices applied, less human disturbances thus allowing the stand to attain its optimum growth as manifested by the plantation studied.

Key words: *biomass, C, CO_2 and sequestration rate*

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INTRODUCTION

Scientists and environmentalists warn that global warming and climate change threaten world security today. The Intergovernmental Panel for Climate Change (IPCC) defined climate change as "a change in climate attributed directly and indirectly to human activity that alters the composition of the global atmosphere in addition to natural climate variability observed over comparable time periods" (*Houghton 2005; Lasco and Pulhin 2006*). This is brought about by excessive accumulation of greenhouse gases (GHG), particularly carbon dioxide in the atmosphere, which leads to global warming. The 2007 IPCC Fourth Assessment Report stated that 11 of the 12 years in the period (1995-2006) rank among the top 12 warmest years in the instrumental record (since 1985). Warming in the last 100 years caused about a 0.74 ºC increase in global average temperature while sea level rose at an average rate of about 1.8 mm $year^{-1}$ during the years 1961-2003. The rise in the sea level during 1993-2003 was at an average rate of 3.1 mm $year^{-1}$. Modeled scenarios suggested that by 2100, average global temperature will increase from 1.1 to 6.4 ºC while sea level is expected to rise by 18-59 cm.

Forests play a crucial role in the global carbon cycle. They serve as carbon sinks by assimilating CO_2 through biomass build up or as a carbon source by releasing it through deforestation, burning or decay (*Watson et al. 2000*). The potential role of forests, particularly tropical forests, to sequester carbon is primarily thru reforestation, agroforestry and conservation of existing forests (*Brown et al. 1996; Lasco and Pulhin 2003*). Great attention is directed toward tropical forest management to offset carbon emission due to its cost effectiveness and high potential rate of carbon uptake associated with environmental and social benefits.

In the Philippines, there are many areas that can potentially serve as carbon sinks (*Lasco and Pulhin 2006*). In 1998, it was estimated that the Philippine forestlands are net sinks of greenhouse gases absorbing about 107 Mt of CO_2, roughly equal to the total Philippine GHG emissions (*Lasco and Pulhin 2003*). One of the forest types considered to have a major potential to sequester atmospheric carbon are plantation forests. It is estimated that tree plantations in the Philippines sequester carbon at the rate of 2.6 million Mg $year^{-1}$. If these plantations were allowed to grow for ten years, these can sequester up to 260 million Mg of carbon, although this is a very optimistic calculation (*Lasco and Pulhin 2003*). The sequestration potential of a given tree plantation varies in terms of species, age and silvicultural practices applied, which can enhance the growth of trees and increase their biomass (*Lasco and Pulhin 1998*) and its rotation period (*Schroeder 1992*). Thus, this study was conducted to further validate the aforementioned findings.

The study was initially conducted in 2000 to investigate the potential of a mahogany (Swietenia macrophylla King.) plantation to absorb carbon in its biomass (*Racelis 2000*). The research yielded excellent results, which further proved that Mahogany forest plantation has huge potential to store vast amounts of C given good site condition, sustained maintenance, and minimal disturbances or destruction from anthropogenic factors. However, the study did not consider the C sequestration rate of the stand due to lack of baseline data. To this effect, it is necessary to measure the assimilation rate of the plantation to determine the optimum level at which it accumulates carbon through time. Hence, this study was conducted mainly to estimate quantitatively the capacity of a mahogany plantation to store and sequester carbon by comparing 2000 data gathered against the 2010 data from the same study site.

MATERIALS AND METHODS

Description of the Study Site

The Mahogany plantation is located inside the Mount Makiling Forest Reserve (MMFR) (**Figure 1**). It was established in 1940 as a demonstration forest and is now part of the Permanent Field Laboratory Area 3 of the College of Forestry and Natural Resources, University of the Philippines Los Baños. It is located 14°08' North and 121°11' East and lies 65 km South of Manila. It has a total land area of 0.7 ha with an elevation of about 199 m asl. Its topography is characterized by moderately rolling terrain with a clay loam type of soil. The area has tropical monsoon climate with distinct dry and wet season. Specifically, it belongs to the Climatic Type I under the Corona Classification, which is wet from May to December and dry from January to April. It has an annual mean rainfall and temperature of 2,397 mm and 24°C, respectively (*Cruz et al. 1991*).

Stand Structure

A total of 387 trees were inventoried in the study site at an average of 48 trees per transect. The trees have an average diameter at breast height (DBH) of 25 cm, with

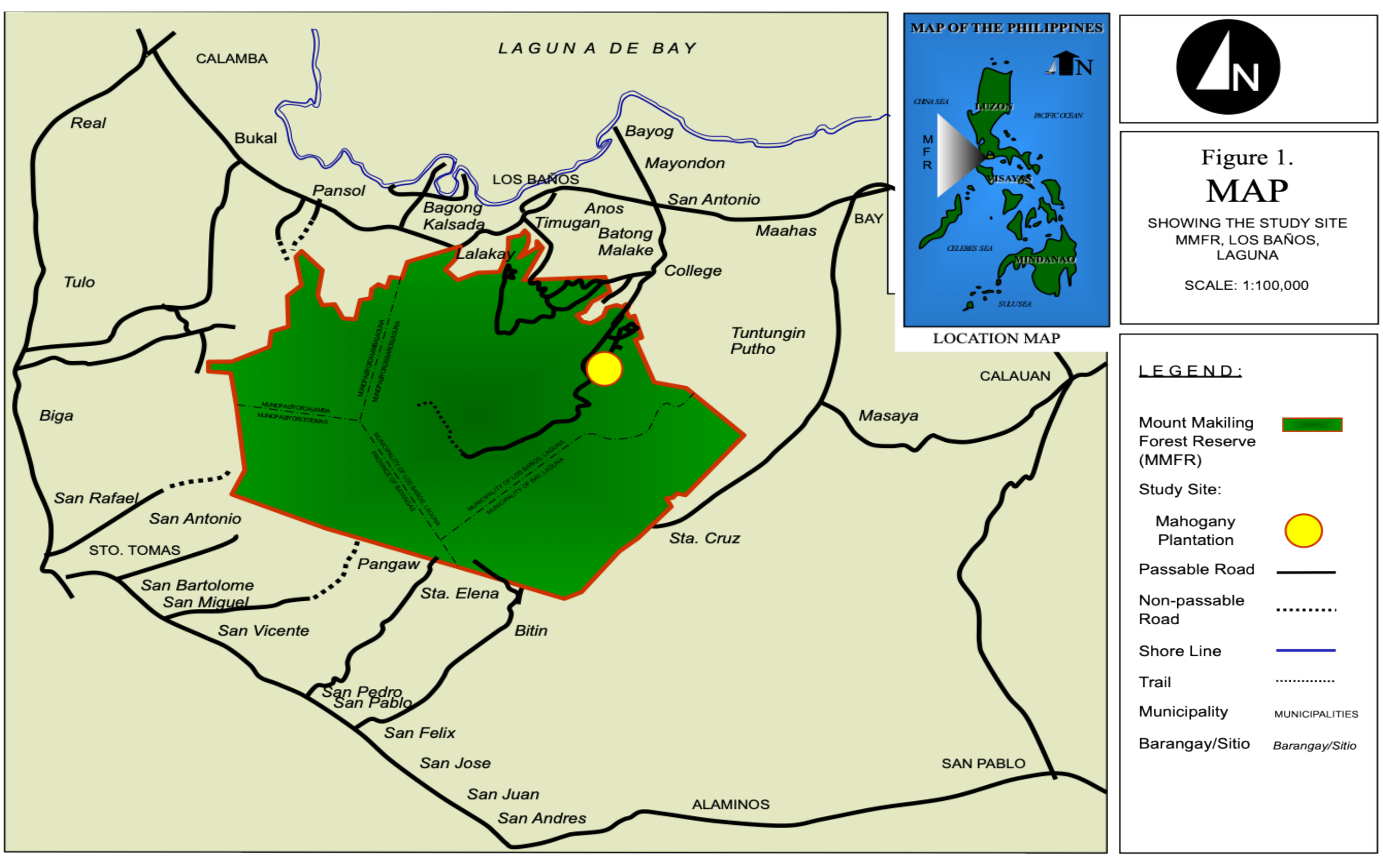

Figure 1. The study site at the Mount Makiling Forest Reserve (MMFR), Los Baños, Laguna, Philippines.

a mean total height of 19.56 m and merchantable height of 6.18 m. About 7% of trees measured have a DBH ≥ 60 cm which is equivalent to 26 individuals. The largest DBH tree recorded within the stand is 116 cm. The stand has a density of 967 trees ha^{-1} and a basal area of 47.0 m^2 ha^{-1}. Silvicultural treatments applied include light thinning and regular removal of vines to reduce competition and mortality.

Biomass Sampling and Computation

The study applied belt transect sampling, the same sampling method used in the 2000 study (*Racelis et al. 2008*). To minimize sampling error and increase the precision of data gathered, the number of transects and sampling plots were increased from three to eight transects and from three to five sampling plots per transect. Transects were established and replicated systematically adjacent to each other covering almost the entire stand. The nearby road served as the baseline where transect central axis emanates. A 50-m plastic twine was tied from the baseline to the end of the specified transect length and was used to ensure that the specified dimension is maintained. Each side of the transect measured 5 m from the central axis for a total width of 10 m. A total of 8 transects were established within the stand, as illustrated in a lay-out of a transect and sampling plots per C pool with corresponding dimension per plot. (**Figure 2**). Complete enumeration of all trees with DBH ≥ 5 cm was done in each transect including standing dead trees and fallen logs for coarse woody debris (CWD) estimation. For live trees, data gathered included DBH, merchantable height, total height, and crown diameter. CWD sampling measured the DBH and total height of the tree. Five sampling plots of varying dimensions were systematically established inside each transect to determine biomass density of understorey/herbaceous (U/H) vegetation, necromass and ground litter (NL), and soil organic carbon (SOC). The study used destructive sampling to measure the biomass density of U/H and NL by determining the fresh and over dry weights of sampled specimens. Sampling of U/H was done in a 2 m x 2 m plot by harvesting trees with DBH <5 cm and other vegetation. Necromass measurement (ground litter and some woody materials) was carried out in a 1 m x 1 m plot laid-out at the center of U/H sampling plot.

Sampling for soil carbon was done in a pit located at the center of both sampling plots for U/H and NL. Composite soil samples were collected at varying depths: 0-5 cm; 5-10 cm; 10-20 cm and 20-30 cm to determine the organic matter content as basis for the soil organic carbon. Soil bulk density was determined from

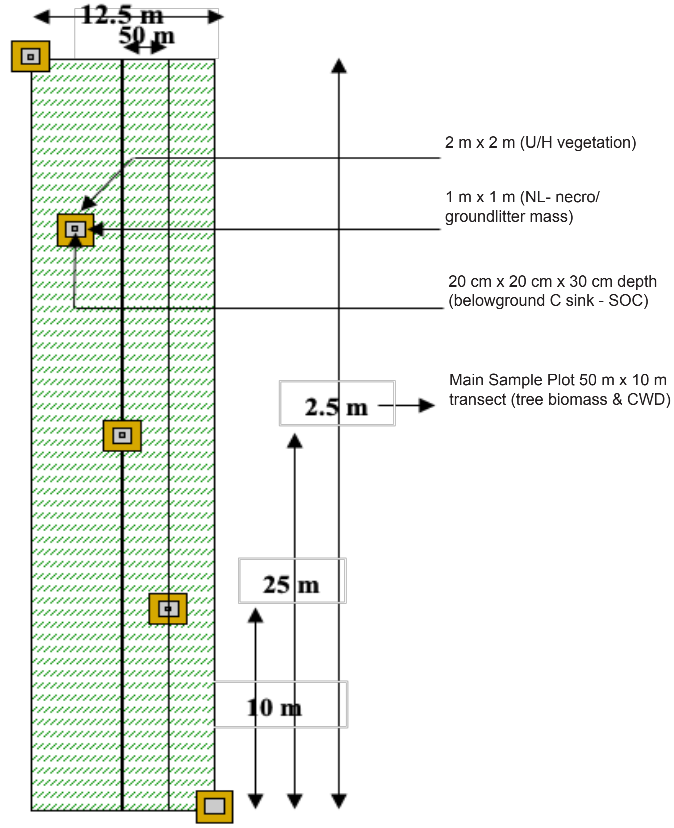

Figure 2. Experimental lay-out of sampling plots per transect.

soils sampled at randomly selected spots within the stand using a metal cylinder of known volume. From the soil samples gathered, the following data were obtained: fresh weight; oven dry weight; moisture content; organic matter content; and soil bulk density. The biomass and carbon content of each carbon pool were computed using Brown formula (*Brown 1997*). The percent carbon value was based on the carbon analysis of wood and roots samples done at the International Rice Research Institute (IRRI) laboratory. Biomass, carbon, and CO_2 contents for each carbon pool were computed using the following formula:

Biomass Calculation

Trees biomass (TB). Tree biomass was calculated using the allometric equations developed by *Brown* (*1997*) for tropical moist forest:

For trees with DBH that ranges from 5 – 60 cm.

$$Y = EXP(-2.134+2.530*LN(DBH))$$

For trees with DBH >60 cm

$$Y = 42.69-12.8*DBH+1.242*(DBH)^2$$

Where Y = tree biomass (kg)

DBH = diameter at breast height (cm)

Biomass per tree was converted to ton or Mg measurement unit: 1 ton = 1 Mg

Total TB in Mg ha^{-1} was derived using the formula below:

$$T_{TB} = \frac{\sum \text{Biomass of all trees in a transect (ton)}}{\text{Area of the transect (m}^2\text{)}} \times \frac{10{,}000 \text{ m}^2}{1 \text{ ha}}$$

U/H vegetation

$$\text{U/H density} = \frac{\text{Oven dry weight/area (g m}^{-2}\text{) x 10,000 m}^2\text{ ha}^{-1}}{10^6 \text{ grams ton}^{-1}}$$

Necromass. The biomass for CWD (standing dead tree and fallen logs) was determined using the formula for tree biomass computation presented above.

$$\text{While for ground litter} = \frac{\text{Oven dry weight/area (g m}^{-2}\text{) x 10,000 m}^2\text{ ha}^{-1}}{10^6 \text{ grams ton}^{-1}}$$

Root biomass. Root biomass was computed based on tree biomass of individual tree using *Pearson et al.* (*2005*) formula:

Root Biomass = EXP(-1.0587+0.8836*LN(TB))

Where TB= Tree Biomass

Carbon Density

Plant C. Plant biomass was converted to the equivalentamount of carbon by multiplying % carbon content of each sink. The 2000 study indicated the various percentage of carbon obtained in different pools in the stand (**Table 1**).

Table 1. Percent carbon stored in different pools in the stand.

Sinks	Percentage
Wood	41.60
UH	43.40
NL	38.40
CWD	38.47
Roots	46.90

Source: *Racelis 2000*

Soil Organic Carbon (SOC). Bulk density (BD) was computed using the formula:

BD (g cm^{-3}) = Dry weight of soil (g)/Volume of cylinder (cm^3)

The dry weight of soil and the equivalent SOC were determined using the following formula:

- Volume of 1 ha soil= 100 m x 100 m x 0.3 m
- Weight of soil (Mg)= Bulk Density x Soil Volume
- SOC = Weight of soil (Mg) x % SOC

Carbon Dioxide (CO_2) Content. Carbon content per sink was converted to CO_2 density in Mg ha^{-1} using the formula below:

CO_2 = C stored in Mg ha^{-1} x 44/12

Where:
CO_2 = 1 molecule of Carbon and 2 molecules of Oxygen
Atomic weight C = 12 O = 16
Weight of CO_2 is C + 2*O = 43.999915 or 44

The ratio of CO_2 to C is 44/12 (http://www.plant-tree.org/resources/calcula...-naka-cache-Katulad, Feb. 24, 2014)

Total CO_2 = Total carbon per sink x 44/12.

* The total C and CO_2 stock of the stand was computed by summing up the contribution of the different C pools.

Sequestration Rate. Annual sequestration rate was determined by getting the biomass, C stored and CO_2 content of the current measurement (2010 data) minus the initial measurement (2000 data) divided by the number of years that elapsed.

$$\text{Sequestration rate} = \frac{\text{Current data (2010) – previous data (2000)}}{\text{Number of years that elapsed}}$$

RESULTS AND DISCUSSION

Biomass and Carbon/CO_2 Density

Mahogany plantation has a total carbon stored in its biomass amounting to 542.58 Mg ha^{-1} or 1,989.41 Mg ha^{-1} of CO_2. Aboveground biomass has the highest percentage of carbon accumulation followed by belowground C pools and the lowest is ground biomass (**Table 2**). The tree component exhibited the highest percentage (69%) of deposited C or CO_2 in its biomass followed by SOC (13%) (**Figure 3**).

The total amount of carbon stored in Mahogany plantation (542 Mg ha^{-1}) is relatively higher than the estimate given by *Lasco* (*2002*) for natural forests in SE Asia, which typically contain a high C density up to 500 Mg ha^{-1}. However, it falls in the upper range of biomass densities (446-1,126 Mg ha^{-1}) of old-growth forests in other parts of the Philippines (*Lasco et al. 2008*). The result is midway within the C storage range as reported from Malaysian forests. Malaysian forests have C storage

Table 2. Total biomass, C and CO_2 content in the different sinks of Large Leaf Mahogany plantation.

Carbon sink	Biomass density (Mg ha^{-1})		C stored (Mg ha^{-1})		CO_2 (Mg ha^{-1})	
Aboveground biomass		(%)		(%)		(%)
Tree biomass	902.20	80.58	375.32	69.17	1,376.16	69.17
U/H vegetation	7.45	0.67	3.23	0.60	11.85	0.60
Sub-total	909.65	81.25	378.55	69.77	1,388.01	69.77
Ground biomass						
NL	39.98	3.57	15.35	2.83	56.29	2.83
CWD	43.64	3.90	16.79	3.09	61.55	3.09
Sub-total	83.62	7.47	32.14	5.92	117.84	5.92
Belowground C sink						
Root biomass	126.34	11.28	59.26	10.92	217.27	10.92
SOC			72.63	13.39	266.29	13.39
Sub-total	126.34	11.28	131.89	24.31	483.56	24.31
Total	1,119.61	100.00	542.58	100.00	1,989.41	100.00

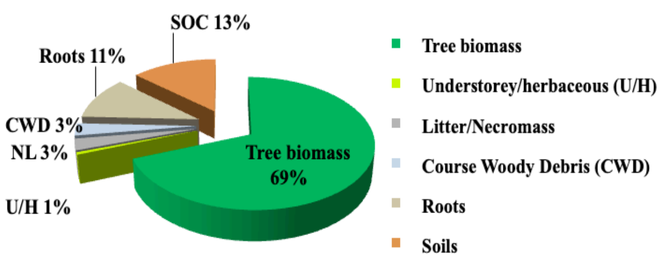

Figure 3. Percent C distribution among carbon sinks in the Mahogany plantation.

ranging from 190-880 Mg ha^{-1} or an average of 364 Mg ha^{-1} combining vegetation and soil (*Abu Bakar 2000*). Among these types of forests, swamp forests (880 Mg ha^{-1}) has the highest C stored followed by mangrove (450 Mg ha^{-1}). Meanwhile, the result is way above those in Indonesia and even C stocks derived from different forest types in the Philippines. In Indonesia, the highest reported C stored came from an undisturbed forest which is 390 Mg ha^{-1} (*Hairiah and Sitompul 2000*). In the Philippines, particularly in Palawan province, as reported by *Lasco et al.* (*2002*), the amounts of carbon stored from different forest types, are ranked as follows: old growth forest (349.81 Mg ha^{-1})> mossy forest (204.25 Mg ha^{-1}) > residual forest (336.4 Mg ha^{-1}) and > mangrove forest (174.9 Mg ha^{-1}).

Consistent with previous findings (*Pulhin, 2007; Lasco et al., 2004; Lasco et al., 2000; and Zamora, 1999*), tree biomass is the major sink of carbon in this study with a total C of 375 Mg ha^{-1}. It was reported that trees can store large amount of carbon in their standing biomass, especially in stands with larger trees (dbh ≥ 60 cm), and whose biomass is greater than 4 Mg. Large-diameter trees are usually few in number but they can share more than 40% of the carbon in an old-growth stand (*Brown and Lugo 1982; Brown et al. 1992*).

For the belowground C sinks, the stand accumulated a total C of 132 Mg ha^{-1} or 483 Mg ha^{-1} of CO_2 with soil receiving the most carbon deposits (13%). The study has SOC of 72.63 Mg ha^{-1} or 266 Mg ha^{-1} of CO_2. SOC ranked next to tree biomass with the highest C content in the entire stand. Several studies also confirmed soil as the second highest carbon sink in a forest ecosystem (*Pulhin 2007; Lasco and Pulhin 2006*). The SOC value in this study is quite high as compared to the findings of *Pulhin* (*2007*) from the same species of Mahogany (14 Mg ha^{-1} C) and from a second growth forest (13 Mg ha^{-1} C). The result is about 50% higher compared to the SOC measured in the plantations at La Mesa Watershed near Manila, which ranges from 30 to 43 Mg ha^{-1} or an average of 35 Mg ha^{-1}. Moreover, the result corroborates the claim of *Moura-Acosta* (*1996*) that soil carbon plus C of necromass is equivalent to 90 Mg ha^{-1} of the total C of a forest ecosystem. In this study, adding the C values of these two carbon sinks (soils and necromass), it yielded even higher C at 104 Mg ha^{-1}. Comparing further the SOC from this study with similar studies conducted locally, the result is similar, with agroforestry system in MMFR at an average of 77 Mg ha^{-1} C (*Sales 1998; Estrella 1998; and Zamora 1999*).

Brown et al. (*1992*) reported that variations in the rate of SOCs accumulation are due to the differences in species and environmental factors. Some species produce more litter and roots and thus, produce more organic inputs, which eventually influence soil carbon. These species' effects must be considered in plants for enhancing

C sequestration. Further, they added that soil organic matter could recover under forest plantations at rates similar to or faster than secondary forests. It was noted by *Lasco et al.* (2004) that the amount of SOC increases over time. It can be deduced that as vegetation matures, its soil carbon content also increases. Since the study involved a plantation which is considered mature, higher amounts of SOCs can be expected.

For the ground biomass, the study showed a total C of 32 Mg ha^{-1} or 118 Mg ha^{-1} of CO_2 from NL and CWD. The result is quite high compared to the study of *Pulhin* (*2007*) with 13 Mg ha^{-1} C for secondary plantation and only 0.63 Mg ha^{-1} for Mahogany. The higher value may be attributed to the additional C value on CWD which was not considered in other studies conducted. The CWD biomass falls in the lower range of 49.7-59.9 Mg ha^{-1} from a study conducted in mature forest in Eastern Amazonia (*Lasco et al. 2008*). Data on CWD is also deemed critical considering the number of typhoons that visited the study site. The carbon content of dead and fallen trees should be accounted to capture the potential of the entire stand to sequester carbon, otherwise this could lead to underestimation of C pools.

The study further indicated that combining the results of carbon stored in U/H, NL, and soil resulted in 24% of the total aboveground C. The result falls within th*e IPCC SAR WG2* (*1996*) assumption that the sum of the above-mentioned carbon sinks would account for 25% of the total aboveground biomass.

The data showed similar trends of values in biomass, carbon and CO_2 content. As the value of biomass increases, the value of C and CO_2 consequently increases. The higher the biomass produced, the higher the amount of carbon stored and similarly the CO_2 content, which contributed to higher share in the total carbon or CO_2 sequestered. The same findings were observed particularly on biomass and C relationship by several studies done locally (*Lasco et al. 2004; Pulhin 2007; Patricio and Tulod 2010; and Racelis et al. 2008 and 2017*). These observations had been supported by a regression analysis done by *Zamora* (*1999*) and *Racelis et al.* (*2008*) that at 5% level of significance, there was a strong correlation between the amount of biomass produced and carbon stored in trees.

The higher C and CO_2 values obtained from this study further affirm the findings of *Lugo and Brown* (*1992*) and *Brown et al.* (*1992*) that a major fraction of the net accumulation of aboveground carbon in tropical stand appears to occur in the continuous growth of older trees that get progressively larger with age. Based on record, Mahogany trees in MMFR are already 70 years old, which means that they have accumulated considerable amount of biomass through time. Larger trees in a stand, even if they are limited in number, have the major deposits of carbon in a forest ecosystem of about 40% (*Lugo and Brown 1992*) and *Brown et al.* (*1992*). More than 90% of biomass is commonly found in bigger trees (*Guillespie et al. 1992; Lasco et al. 2000; and Lasco et al. 2005*). Trees in mature tropical forests tend to account for more than 30% of the aboveground biomass (*Lugo and Brown 1992; Pinard and Putz 1996 as cited by Watson et al. 2000*). Moreover, it is normal that mature forest species have higher wood density than those of younger trees (*Brown et al. 1992*). In the case of La Mesa Watershed, *Lasco and Pulhin* (*2006*) reported a relatively lesser biomass in the pure Mahogany plantation as it is dominated by small diameter trees with DBH range of 5-12 cm at the maximum.

In addition, the results strongly conforms with the observations made by *Brown et al.* (*1986*) that the net productivity of plantation forests can be high with values of up to about 3 and 10 times that of secondary and mature forests, respectively. These could also be ascribed to the site condition where the species are planted. The Mahogany plantation site is very conducive for growth owing to its ideal elevation and fertile volcanic soil. It has an elevation of 199 m asl, which falls way below the maximum altitude of 600 m asl favorable for species growth (*Hensleigh and Holaway 1988*, *as cited by Lasco et al. 2002*). *Lasco et al.* (*2002*) reported that the poor growth of Mahogany plantation in Central Philippines could be attributed to its higher elevation of 810 m asl. For tree care and maintenance aspects, the plantation is occasionally maintained through weeding and removal of vines in order to reduce competition. Similarly, the study area is situated in a forest reserve where utilization or harvesting of trees is prohibited (unless they are damaged by typhoons or can pose hazard), thus majority of trees and their stand structure are less disturbed and relatively intact. *Lugo and Brown* (*1992*) emphasized that higher values of biomass content are also associated with less human or natural disturbances.

Sequestration Rate

Lasco and Pulhin (*2003*) reported that there is a dearth of data on sequestration rate of vegetation and forest ecosystem as compared to carbon storage. This is primarily because the former requires periodic measurements which are expensive and time consuming. It is also rarely done on short duration, if it occurred it is generally limited to 10-year interval (*Houghton 2005*). This study in particular was able to conduct re-measurements of biomass and carbon storage of Mahogany plantation after 10 years.

The stand gained a total biomass of 430 Mg ha^{-1} equivalent to 222 Mg ha^{-1} C fixed or 813 Mg ha^{-1} of CO_2 from 2000 to 2010 (**Table 3**). For its annual sequestration rate, it registered a biomass build-up of 43 Mg ha^{-1} yr^{-1} equivalent to 22 Mg C ha^{-1} yr^{-1} or 81 Mg ha^{-1} yr^{-1} of CO_2. All carbon pools within the Mahogany stand showed a significant increase in C uptake. In particular, there is a significant leap of C stocking in the biomass of the following sinks, rank as follows: U/H (25x), NL (7x), CWD (3x) and soils (2x>) or from hundreds to thousand percent increase from the initial measurements (**Table 4**). There is a total of 69% increase in C stored in the entire stand a decade after.

The values obtained on biomass, C and CO_2 sequestration rate in this study far exceeded the estimate made by *Lugo and Brown* (*1992*) that a 60-80 year old tropical forest still sequesters C at the rate of 1-2 Mg ha^{-1} yr^{-1} or an average of 1.5 Mg ha^{-1} yr^{-1}. Similarly, the results are comparatively higher than the data on sequestration rate obtained in Indonesia where Acacia spp. exhibited the highest annual C increment of 12.50 Mg ha^{-1} yr^{-1} from reforestation and afforestation areas. On the average, annual C sequestration rate of different forest types or tree species is 5.06 Mg ha^{-1} yr^{-1}. Specifically, mahogany has C accumulation of 3.99 Mg ha^{-1} yr^{-1} while a stand of Dipterocarp species in a timber state in Java, has 2.89 Mg ha^{-1} yr^{-1} (*Hairiah and Sitompul 2000*). The C accumulation capacity in this study is 84% higher than the average sequestration rate of Mahogany species in Indonesia. The higher sequestration rate in this study may be also attributed to the prevalence of younger regenerations or understorey vegetation which compensates the loss of older trees due to mortality and decay. Similarly,necromass, CWD and SOC were included in the assessment that could account for higher C intake.

However, the values obtained are quite close to the findings of *Lasco and Pulhin* (*2003*) that carbon sequestration ranges from >1 Mg ha^{-1} yr^{-1} in natural forest and < 15 Mg ha^{-1} yr^{-1} in some plantations or close to 17.5 Mg ha^{-1} yr^{-1} C for fast-growing species. In Iloilo province, Philippines, *Lasco* (*2002*) reported *Acacia crassicarpa* with the highest C mean annual increment (MAI) of 18 Mg ha^{-1} yr^{-1} among 11 tree species planted whose MAI ranges from 0.07-17.53 Mg ha^{-1} yr^{-1} . In Mt. Makiling, the average MAI in a Mahogany and Dipterocarp reforestation project, 80 years after planting was 2.8 Mg ha^{-1} yr^{-1} (*Racelis et al. 2008*). In Nueva Ecija Province, reforestation projects planted with fast-growing exotic species have a MAI ranging from 0.30-3.73 C Mg ha^{-1} yr^{-1}. These values are very low compared with other Philippine forests, tree plantations or similar vegetative cover in other parts of the country. Fast growing species planted in a reforestation project in Leyte Province have a lower C MAI ranging from 0.7- 9.0 Mg ha^{-1} yr^{-1}. Again,

Table 3. Summary of biomass production, C and CO_2 storage from 2000 versus 2010 data.

Carbon sink	2000 data			2010 data		
	Biomass (Mg ha^{-1})	C (Mg ha^{-1})	CO_2 (Mg ha^{-1})	Biomass (Mg ha^{-1})	C (Mg ha^{-1})	CO_2 (Mg ha^{-1})
Aboveground biomass						
Tree biomass	585.03	243.37	892.37	902.20	375.32	1,376.16
U/H vegetation	0.29	0.13	0.47	7.45	3.23	11.85
Sub-total	585.32	243.50	892.84	909.65	378.55	1,388.01
Ground biomass						
NL	5.31	2.04	7.47	39.98	15.35	56.29
CWD	13.76	5.29	19.40	43.64	16.79	61.55
Sub-total	19.07	7.33	26.87	83.62	32.14	117.84
Belowground C sink						
Root biomass	85.20	39.96	146.52	126.34	59.26	217.27
SOC		30.05	110.17		72.63	266.29
Sub-total	85.20	70.01	256.69	126.34	131.89	483.56
Total	689.59	320.84	1,176.40	1,119.61	542.58	1989.41
Amount sequestered				430	222	813
Sequestration rate yr^{-1}				43	22	81

Table 4. Amount of carbon gained per sink in the Large Leaf Mahogany after 10-year period.

Carbon sink	2010 C Stored (Mg ha^{-1})	2000 C Stored (Mg ha^{-1})	Amount increased (Mg ha^{-1})	% increased
Aboveground biomass				
Tree biomass	375.32	243.37	131.95	54
U/H vegetation	3.23	0.13	3.10	2,385
Sub-total	378.55	243.50	135.05	
Ground biomass				
NL	15.35	2.04	13.31	652
CWD	16.79	5.29	11.50	217
Sub-total	32.14	7.33	24.81	
Belowground C sink				
Root biomass	59.26	39.96	19.30	48
SOC	72.63	30.05	42.58	142
Sub-total	131.89	70.01	61.88	
Total	542.58	320.84	221.74	69

the difference in values was attributed to the poor site condition due to the presence of *Imperata* and *Saccharum* spp. of grasses that hampered the better growth of the target species.

The capacity of forest plantation to store carbon also varies with age and species. In Indonesia, 8-11 year-old plantations have a mean C of 62 Mg ha^{-1} as compared to a 32-45 year-old plantations with an average C stored of 201.08 Mg ha^{-1}. Older plantations have higher C accumulation than younger ones. However, in terms of sequestration rate per year the amount is comparable. Younger plantations have MAI of 6.09 Mg ha^{-1} yr^{-1} while older plantations have an average of 5.74 Mg ha^{-1} yr^{-1} (*Sakurai et al. 1994*). In Malaysia, results of afforestation trials registered a C MAI that ranges from 0.14 to 8.70 Mg ha^{-1} yr^{-1}. Most of the tree species accumulate C less than 5 Mg ha^{-1} yr^{-1}.

CONCLUSIONS AND RECOMMENDATIONS

Mahogany plantation has a good potential to store and sequester carbon given favorable environmental condition and appropriate management interventions. Aside from its high capacity to accumulate carbon in its biomass, it can sequester significant amounts of carbon over time owing to its relatively faster growth rate. As mentioned by *Lugo and Brown* (*1992*), higher biomass values are often associated with minimal or absence of human-induced or natural disturbances. Similarly, the presence of mature and large-diameter trees have significant contribution in the amount of carbon stored in the entire plantation.

The study revealed that a Mahogany plantation can store up to 542 Mg ha^{-1} of C with a sequestration rate of 22 Mg ha^{-1} yr^{-1}. Therefore, converting the estimated 1.8 million ha of grassland areas in the Philippines into Mahogany plantation could potentially result in C uptake of 975.6 million Mg with a sequestration rate of 22 Mg ha^{-1} yr^{-1} of C. Thus, this could potentially offset 30% of the total national annual C emission of 128.6 million Mg $year^{-1}$. Moreover, conservation of mature forest similar to this study could prove to be an effective and more economical way to embark on carbon offset program. Although, it has higher mortality rate due to natural attrition, the decrease in biomass is compensated by regenerations and recruitment of new vegetative cover.

It is also recommended that protection efforts should be actively pursued in plantations within forest reservations to conserve C pools. This is in addition to the attendant benefits derived from forest conservation such as increased biodiversity, enhanced aesthetics and recreation, and better livelihood opportunities to local communities.

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