Journal of Environmental Science and Management 12(1):1-13 (June 2009)
ISSN 0119-1144

Carbon Budgets of Forest Ecosystems in the Philippines

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ABSTRACT

Forest ecosystems can both be sources and sinks of carbon. Here, we review the state of knowledge on carbon budgets of Philippine forests types. The following are the main findings of the review: Carbon (C) density in aboveground biomass (AGB) declines by about 50% after logging, deforested areas covered with grasses and annual crops have C density less than 15 MgC/ha, conversion of natural forests to tree plantations and perennial crops reduce C density by about 50%, reforestation activities in degraded areas increase C density with a mean annual accumulation of up to about 10 MgC/ha/yr for fast growing species and 3 MgC/ha/yr for slow growing species, and silvicultural treatments such as mycorrhizal inoculation can increase C accumulation. In spite of the new information generated in the last few years, there is still a great need to quantify carbon stocks and rate of sequestration of the various forest types in the country.

Key words: *carbon credits, carbon sequestration and forest ecosystems*

INTRODUCTION

It is estimated that about 60 Gt C is exchanged between terrestrial ecosystems and the atmosphere every year, with a net terrestrial uptake of about –0.9 ± 0.6 Gt C per year for 2000 to 2005 (Denman *et al*. 2007) . Land use, land-use change and forestry (LULUCF) activities, mainly tropical deforestation, are significant net sources of CO_2, accounting for 1.6 Gt C/yr of anthropogenic emissions. On the positive note however, tropical forests have the largest potential to mitigate climate change amongst the world's forests through conservation of existing carbon (C) pools (e.g. reduced impact logging), expansion of C sinks (e.g. reforestation, agroforestry), and substitution of wood products for fossil fuels (*Brown et al. 2000*). In tropical Asia, it was estimated that reforestation, agroforestry, regeneration and avoided deforestation activities have the potential to sequester 7.50, 2.03, 3.8-7.7, and 3.3-5.8 Gt C between 1995-2050 (*Brown et al*. 1996).

There is increasing interest in forestry projects to help mitigate climate change in the Philippines especially under the emerging carbon market such as the CDM (*Villamor and Lasco 2006; Lasco and Pulhin 2006*). Recent studies have shown the great potential of tree plantations and agroforestry systems to sequester carbon. In addition to its role in mitigation, agroforestry systems can help the smallholders adapt to climate change (*Verchot et al. 2007*).

According to the Intergovernmental Panel on Climate Change (IPCC), the land available for afforestation options depends on the price of carbon and how that competes with existing or other land-use, financial returns, barriers to changing land uses, land tenure patterns and legal status, commodity price support, and other social and policy factors (*Nabuurs et al. 2007*). In the short-term (2008-2012), it is estimated that up to 5.3 M ha is available in developing countries for afforestation/ reforestation under the Clean Development Mechanism (CDM).

In spite of the importance of forest ecosystems to the carbon cycle, there is little information on the effects of land use change and management activities on the carbon budgets of these ecosystems in the tropics. Here we determined the carbon budgets of forest ecosystems in the Philippines in response to different land use change and management activities such as harvesting and reforestation using the data generated from the studies previously conducted on carbon stocks assessment.

FOREST LAND USE CHANGE IN THE PHILIPPINES AND THE C CYCLE

Rate of Deforestation and Landuse/Cover Change in the Philippines

The last few decades have seen massive deforestation and landuse/cover change in the tropics and the Philippines was no exception. When the Spanish colonizers first set foot in the Philippines in 1521, 90% of the country was covered with lush tropical rainforest (ca. 27M ha out of 30M total land area). By the year 1900, there were still 70% or 21M ha of forest cover (*Garrity et al. 1993; Liu et al. 1993*). However, by 1996 there were only 6.1 M ha (20%) of forest remaining (*FMB 1997*). Thus, in the last century alone, the Philippines lost 14.9 M ha of tropical forests or an average of about 150,000 ha/yr (**Table 1**).

Table 1. Deforestation rates in the Philippines in the 20th century.

Period	Years	Forest Lost (ha)	Rate (ha/yr)
1900-1934	35	4,000,000	114286
1935-1988	54	9,700,000	179630
1989-1996	8	1,200,000	150000
Mean			147972

Forest loss data adapted from Lasco and Pulhin (2000)

Historically, logging activities by big companies have been the most important driving forces in the loss of forest cover in the country. At the height of the logging activities in the 1970s, there was a peak of 471 Timber License Agreement (TLA) holders in the Philippines controlling an aggregated area of more than 10M ha, a staggering one third of the total land area of the country (*Lasco et al. 2001*). This indicates how a few companies gained control over much of the country's natural resources. Since the mid 1980s the number of TLAs has steadily declined and by 2005 there were only 17 TLAs covering an area of 778943 ha (*FMB 2006*).

While logging operations were supposed to be sustainable through the application of the Philippine Selective Logging System (PSLS), in many cases commercial logging sets into motion a process that eventually lead to deforestation and severe degradation of forestlands (*Lasco et al*. 2001c). That is, logging roads facilitate establishment of communities inside the forest area leading to other activities such as shifting cultivation and further cutting which is often illegal.

However, the ultimate driving forces of deforestation are more complex than simply blaming loggers and shifting cultivators. As *Kummer* (*1992*) rightly pointed out, deforestation in the Philippines is tied up to the larger issues of corruption, poverty, high population density, and migration to upland areas.

C budgets of forest ecosystems and their potential for C sequestration

Tropical forests contain a significant amount of C in the biomass, necromass and in the soil. In tropical Asia, about 41-54 Pg C and 43 Pg C are found in vegetation and soils, respectively (*Dixon et al. 1994*). However, annual C flux from tropical Asian forests is estimated at -0.50 to – 0.90 Pg/yr.

In the Philippines, our previous estimates of C pool of the forest lands are in the order of 750 Tg C (*Lasco 1998*), 1105 Tg C (*Lasco and Pulhin 1998*), and 1140 Tg C (*Lasco and Pulhin 2000*). The first estimate is much lower than the others because it excludes the grasslands and brushlands. Using the COMAP model, we estimated that C stocks of forest lands are around 1134 for the year 2000 (*Lasco and Pulhin 2001a*). Thus, these studies confirm that the C pool of Philippine forest lands at present is in the order of about 1100 Tg C. In relative terms, total C stored in forest lands is equivalent to about 40 times the 1994 net C emissions of the Philippines.

Based on the 1996 IPCC Revised Methodology for Greenhouse Gas Inventory, the contribution of the LUCF sector in the Philippines has shown a swing from being a net source in 1990 to a strong net sink in 1998 (**Table 2**). This adjustment is due largely to the changes in activity data used and the availability of country-specific data for the sector.

Table 2. Total emissions from the LUCF sector of the Philippines (Gg CO_2 equivalent).

Source	1990 inventory (1997 US Country Studies)	1990 inventory (1998 ALGAS)	1994 inventory (1999 Philippine Nat. Comm.)	1998 inventory (Lasco and Pulhin 2001b)
Change in Forests and biomass stocks	-48654	2622	-68323	-190522
Forest and grassland conversion	120738	80069	68197	46,624
Abandonment of managed lands	-1331	-1331	Not determined	Not determined
Net Emissions	70753	81360	-126	- 142,007
Total Philippine emissions	128,620	164,103	100,738	100,738
% of total Philippine emissions	55.01	49.58	-0.13	-142

References: Francisco 1997; Murdiyarso 1996; ADB 1998; Philippines' Initial National Communication, 1999

In terms of rate of sequestration, our studies showed that the Philippines forests sequester around 7.1 to 27.2 Tg C/yr (*Lasco 1998; Lasco and Pulhin 1998; Lasco and Pulhin 2000*).

CARBON BUDGETS FOLLOWING LOGGING OPERATIONS IN NATURAL FORESTS

As discussed earlier, logging operation is primarily responsible for the conversion of primary forests into other land uses in the Philippines. Destructive logging and subsequent agricultural conversion has vastly depleted the natural forests resulting to emergence of millions of hectares of degraded lands in the country.

Coupled with such conversion of primary forests into other land uses is the reduction of the carbon stocks. This claim has been verified by the results of the study we conducted in Mindanao where we assessed the amount of carbon stored in undisturbed forests and logged-over forests at various years after logging (YEAL). Results showed that logging caused a 50% decline of the carbon density when primary forests are converted into secondary forests (*Lasco et al. 2001c*). Thus, from an original carbon density of 198 Mg, it has dramatically decreased to 99 Mg only. This is consistent with the findings of *Brown and Lugo* (*1984*) where carbon density is observed to decline by 22-67% once the undisturbed closed broad leaf forest in Asia is logged (**Table 3**).

The dramatic decline of carbon stocks during logging operation is caused by the destructive way of harvesting timber. For instance in Malaysia, extracting 8-15 trees (80 m^3; ca 22 MgC/ha) from the forests is found to damage as much as 50% of the remaining trees (*Putz and Pinard 1993*). Out of the initial 348 MgC/ha, 95 MgC/ha are damaged which eventually die. These dead trees slowly release carbon in the atmosphere during decomposition. In the Philippines, for every tree cut with diameter at breast height (DBH) of more than 75 cm, 1.5 and 2.6 trees are damaged in favorable and unfavorable conditions, respectively (*Weidelt and Banaag 1982*).

Table 3. Biomass and C (in parenthesis) density of tropical forests in Asia (Brown and Lugo, 1984).

	Closed-broadleaf (Mg/ha)	Closed-conifer (Mg/ha)	Open forest (Mg/ha)
Undisturbed -productive	196.3 (98.2)	144.9 (72.5)	79.0 (39.5)
Logged	93.2 (46.6)	112.5 (56.3)	26.32 (13.16)
% Decline	53	22	67

Putz and Pinard (*1993*) however argued that logging damage can be significantly reduced by directional felling and well-planned skid trails. Consequently, such reduction in logging damage translates into reduction in C emission. These practices are collectively known as reduced impact logging (RIL). The effect of RIL on C conservation has been thoroughly investigated in a study conducted in Sabah, Malaysia as reported by *Pinard and Putz* (*1997, 1996*).

CARBON BUDGETS FOLLOWING CONVERSION FROM FOREST TO NON-FOREST COVER

Impact of Deforestation to Carbon Budgets

While deforestation is a major land-use change in the Philippines, there are no studies that directly track the change in C budget during the deforestation process. However, there are studies that have quantified the C stocks in deforested lands, typically covered with grasslands or annual crops. Based on our estimates, grasslands have C density of 1.7 to 13.1 Mg/ha, while crop lands contain 3.1 to 12.5 Mg/ha (**Table 4**). While these land uses contain carbon, their values are way below than the amount of carbon present in a primary forest (518 Mg/ha). Results indicate that there is a huge amount of carbon lost once deforestation takes place. From a carbon density of 518 Mg/ha it has dramatically reduced to 3.1-13.1 Mg/ha which represent 0.6 to 2.5% only of the original carbon of the primary forest.

Conversion to Tree Plantations and Perennials Crops

Degraded forest lands due to logging can be planted with forest tree species or perennial crops. While there are no studies that directly measure the change of C stocks as a result of the conversion of natural forests into forest/fruit tree plantation, it is expected that C stocks will decrease with such pathway. A change of C stocks following this land use change can be estimated by comparing the C stocks of the forest/fruit tree plantation with that of a natural forest. However, it should be noted that C densities of tree plantation may vary with age, species and site. Thus, there can be a huge difference in the C density of various tree plantations. **Table 5** shows the C densities of tree plantations in various parts of the country. Results from these studies reveal that tree plantations in various parts of the country have C densities of around 35 Mg C/ha to 264 Mg C/ha. Similar to grasslands and croplands, these values are way below the C density value of the natural forest which is 518 Mg/ha. C density values of the tree plantations represent only 7-51% of the carbon density of the natural forests. These findings are found to be consistent with the estimates made in Indonesia where agroforestry and plantation farms have C stocks that represent around 4-66% that of the C stored in an undisturbed forest (*Lasco 2001*).

Even if the species used for plantation development are fast growing, C stored in the natural forests is observed to be far higher than the C contained in tree plantations. For instance

Table 4. Above ground biomass density of grasslands and annual crops in the Philippines.

Land cover	AGB Carbon density (Mg/ha)	Reference
Imperata sp.	8.5	Lasco *et al*., 1999
Sacharrum sp.	13.1	Lasco *et al*., 1999
Rice	3.1	Lasco *et al*., 1999
Sugarcane	12.5	Lasco *et al*., 1999
Banana	5.7	Lasco *et al*., 1999
Imperata sp.	1.7	Biomass from Lachica-Lustica, 1997; C content = 45% (Lasco and Pulhin, 2000)

Table 5. C density of tree plantations in the Philippines (from Lasco et al. 2000a).

Category	Carbon density (Mg/ha)	% of Natural forest
Mahogany	264	51
Legumes	240	46
Dipterocarp	221	43
Acacia sp.	81	16
Teak	35	7
Natural forest	518	

Mindanao, tree plantations of fast growing species with varying ages contain C density of around 3.65 Mg/ha to 54.32 Mg/ha while the Dipterocarp natural forest contains 119.43 MgC/ha. C density values of tree plantations represent 3-45% only of the C density of a natural dipterocarp forest (**Table 6**). Results indicate that in terms of carbon, it is not worth cutting down the natural forests and replace it with tree plantations. Natural forests contain huge amount of carbon thus, when trees are harvested these same amount of carbon stored in the ecosystem will be released to the atmosphere. While the new trees as represented here by the tree plantation species will accumulate carbon through time, it may take a while before they can approximate the C density of the natural forests they replace. Commercial tree plantations in the Philippines of fast growing species sequester C at the rate of 0.50-7.82 MgC/ha/yr (**Table 6**).

In degraded upland areas where people are present, agroforestry is the strategy used to develop the area. Agroforestry systems have been widely promoted as an alternative technology to slash-and-burn farming. They involve planting of trees and perennials in conjunction with agricultural crops. In the Philippines, there are various forms of agroforestry systems that exist (*Lasco and Lasco 1989*). These include: (1) indigenous agroforestry system (Ikalahans, Hanunuos and Naalad, indigenous multistorey systems and the rice terraces-forest system); (2) alley cropping; (3) multistorey systems; (4) boundary planting; (5) windbreak systems; (6) taungya system; (7) PICOP system; and (8) Silvipastoral system. Considering the differing crops these systems may contain, C density values of agroforestry vary.

Carbon stocks assessment of different agroforestry systems were undertaken in the Philippines. For instance, *Lasco and Suson* (*1999*) revealed that a *Leucaena leucocephala* fallow field in Cebu, Philippines has a mean C density of 16 MgC/ha during its 6-year cycle (**Table 7**). In *1999*, *Zamora* assessed the C stored in a coconut-based multistorey system in Mt. Makiling and found that the ecosystem had a C density of 39 MgC/ha. In Leyte province, (*Lasco et al. 1999*) reported that a mature coconut plantation contained 86 MgC/ha in above-ground biomass.

Compared with the natural forests being replaced by the agroforestry systems, the latter have lower C densities. The C density of *Leucaena leucocephala* fallow field in Cebu is a mere 3% of the C density of the natural forests (518 Mg/ha). The coconut-based multistorey system in Mt. Makiling and the mature coconut plantation in Leyte on the other hand, represent just 15% and 16%, respectively of the C density of the natural forest.

In terms of carbon contained in the soil, a coconut plantation has soil organic carbon (SOC) that is about 50% lower than the SOC density of

Table 6. C density of tree plantations in Mindanao, Philippines.

Species	Age (Yrs)	AGB (Mg/ha)	MAI Biomass (Mg/ha/yr)	C density (MgC/ha)	C MAI (MgC/ha/yr)	% of Dipterocarp forest
Albizzia falcataria 1	4	69.5	20.20	31.28	7.82	26
A. falcataria 2	5	75.6	11.20	34.02	6.80	28
A falcataria 3	7	96.4	8.40	43.38	6.20	36
	7	8.1	2.20	3.65	0.52	3
A. falcataria 4	9	108.2	5.30	48.69	5.41	41
	9	28.7	3.70	12.92	1.44	11
Gmelina arborea 1	7	85.7	11.30	38.57	5.51	32
G. arborea 2	9	87.4	10.50	39.33	4.37	33
G. arborea 3	9	120.7	9.60	54.32	6.04	45
Dipterocarp*		265.4	4.90	119.43	1.19	

* Harvested 20 years ago; assumed to be 100 years old; Biomass data from Kawahara (1981); C content assumed to be 45% (Lasco and Pulhin 2000)

Table 7. C density and MAI of a *Leucaena leucocephala* fallow field in Cebu, Philippines (from Lasco and Suson 1999).

Years under Fallow	Mean Dry Weight of above-ground biomass (Mg/ha)	% Leaves	C in Biomass (t/ha)	Annual rate of C accumulation (Mg/ha/yr)
1	4.3 d	36.5	2.2	2.2
2	16.1 cd	13.8	8.1	5.9
3	17.6 cd	8.9	8.8	0.7
4	36.4 bc	7.4	18.2	9.4
5	53.8 ab	5.3	26.9	8.7
6	63.6 a	6.1	31.8	4.9
Mean	32		16	5.3

Means in a column with the same letter are not significantly different using DMRT at 0.05.

a natural forest. Results of the study undertaken by Lasco *et al*. (1999) show that coconut plantation has SOC density of 111 MgC/ha while natural forest has SOC density of 191 MgC/ha. Results show that similar to aboveground biomass, SOC is also affected by the change in land use. Carbon in the soil is a significant pool because it has the longest residence time among organic C pools in the forest (*Lugo and Brown 1993*). However, the exact effect of land use change on SOC is largely unknown in tropical forests especially the rates and direction of change.

CARBON BUDGETS FOLLOWING REFORESTATION/AFFORESTATION OF DEGRADED AND DENUDED LANDS

The rapid loss of forests in the Philippines has left millions of hectares of denuded and degraded lands (*FMB 1998*). This has resulted to loss of huge amount of carbon that is stored in the natural forests. As has been discussed earlier, deforested lands have much lower C density than the forests they replace. Aside from carbon that is lost, other environmental services that the forests used to provide are also impaired due to deforestation.

To rehabilitate degraded lands, the Philippines launched massive reforestation programs. Based on records, the Philippines reforested more than 500,000 ha in the 1990s (*FMB 1998*). In most of these reforestation areas, fast growing tree species were used (*Lasco and Pulhin 2000*). Tree plantations are being established at a faster rate not only to rehabilitate degraded lands but also to meet the wood demand of the country.

As these degraded lands are planted with trees, carbon starts to accrue. As trees grow through time, they accumulate carbon in their biomass thereby increasing the amount of carbon stored in the tree plantation areas. As mentioned earlier in this paper, the amount of carbon being accumulated by the reforestation sites depend on the tree species planted, age of tree plantations and the site condition.

There are very limited reports in literature on C density of reforestation/afforestation areas. However, there is a large body of literature on the performance of species planted in reforestation/ afforestation areas. Typically, dbh and height are the main variable measured and reported. Through the use of allometric equations, primarily from the FAO Handbook by *Brown* (*1997*), we attempted to estimate the biomass, C stocks and the rate of accumulation of the different tree plantation species in the different parts of the Philippines.

In Nueva Ecija, C densities of reforestation species range from 3.47 MgC/ha to 48.52 MgC/ ha (**Table 8**). The wide range in C density values derived is due to the difference in age and species. For instance, the lower C density values are those obtained from areas planted with *Acacia auriculiformis* and *Gmelina arborea* whose ages are only six years old while the higher C density values are derived from *Pinus kesiya* plantations that are already 13 years old. In terms of mean annual increment (MAI), tree plantation species have annual carbon accumulation of 0.30-3.73 MgC/ha/yr. These values are very low compared to other Philippine forests and tree plantations.

Table 8. Biomass and C density and MAI of reforestation species in Nueva Ecija, Philippines.

Species	Age (yr)	Ave dbh (cm)	Biomass Mg/ha	MAI Mg/ha/yr	C density Mg/ha	MAI Mg/ha/yr
Acacia auriculiformis 1	6	5.68	7.39	1.23	3.33	0.55
A. auriculiformis 2	6	6.46	9.97	1.66	4.49	0.75
A. auriculiformis 3	9	9.62	42.51	4.72	19.13	2.13
A. auriculiformis 4	9	8.71	32.00	3.56	14.40	1.60
A. auriculiformis 5	9	10.47	46.11	5.12	20.75	2.31
A. auriculiformis 6	9	8.73	39.73	4.41	17.88	1.99
Tectona grandis 1	13	5.50	8.70	0.67	3.92	0.30
T. grandis 2	13	7.36	22.30	1.72	10.04	0.77
Gmelina arborea 1	6	7.33	17.22	2.87	7.75	1.29
G. arborea 2	6	6.80	7.71	1.29	3.47	0.58
Pinus kesiya	13	12.53	107.83	8.29	48.52	3.73
P. kesiya + broadleaf spp.	13	10.10	83.24	6.40	37.46	2.88

Note: age and dbh data from Sakurai *et al*., 1994; biomass computed using the equation Biomass/tree in kg= 21.297-6.953*dbh+0.74dbh^2 for broadleaf species and Biomass/tree= EXP-1.17+ 2.119*LN(dbh) for conifers (from Brown, 1997); %C in biomass= 45% (based on Lasco and Pulhin 2000)

This is due to the poor site conditions in the area which is predominantly covered with *Imperata* and *Saccharum* spp. grasses (*Sakurai et al. 1994*).

In Leyte, a study conducted to determine the C density of *Swietenia macrophylla*, *Acacia mangium* and *Gmelina arborea* reveal that C density values range from 8 MgC/ha to 88 MgC/ha. The smallest C density was obtained from the *S.macrophylla* plantation while the highest C density value came from *A. Mangium* plantation. As regards MAI, tree plantation species accumulate carbon at the rate of 0.7 MgC/ha/yr to 8.0 MgC/ha/yr. Similar to the trend observed in the C density, carbon accumulation of the tree plantation species go along the following order: *A. mangium* > *G. arborea* > *S. macrophylla* (**Table 9**).

Table 9. Carbon density and MAI of reforestation species in Leyte, Philippines (Lasco et al. 1999).

Species	Biomass (Mg/ha)	MAI Biomass (Mg/ha/yr)	C density (MgC/ha)	C MAI (MgC/ha/yr)
Swietenia macrophylla				
1	22.62	2.06	10.18	0.93
2	19.90	1.81	8.96	0.81
3	8.52	0.77	3.83	0.35
Mean	17.01	1.55	7.66	0.70
Acacia mangium				
1	220.93	20.08	99.42	9.04
2	162.93	14.81	73.32	6.67
3	203.64	18.51	91.64	8.33
Mean	195.84	17.80	88.13	8.01
Gmelina arborea				
1	165.09	10.32	74.29	4.64
2	117.01	7.31	52.65	3.29
3	89.92	5.62	40.46	2.53
Mean	124.01	7.75	55.80	3.49

In search of tree species that can be planted in degraded lands pushed the conduct of trial planting of tree species not commonly growing in the Philippines. In Iloilo province, 11 tree species were planted in grassland to test their growth performance by monitoring the dbh and height of the trees. Using the data generated from this study, biomass and C density and MAI were calculated. Results show that after 4 years of planting, C density ranged from 0.30-70.11 MgC/ha while C MAI was generally less than 10 MgC/ha/yr (**Table 10**).

In Luzon, carbon storage and sequestration of four tree plantation sites in Mt. Makiling were estimated. Results showed that biomass density of the 80 year old plantations range from 279.14 Mg/ha to 634.99 Mg/ha (**Table 11**). In terms of C density, tree plantations contained 125.61 Mg/ha to 285.75 Mg/ha. Among the four stands, *Swietenia macrophylla 2* had the greatest carbon accumulation (3.57 Mg/ ha/yr) while the mixture of *Parashorea malaanonan+Dipterocarpus grandiflorus* showed to have the least (1.57 Mg/ha/yr.

Results indicate that in general, carbon stocks of the tree plantations approximate that of the natural forests when the former reach maturity. Estimate of the secondary forest in Mt. Makiling showed that it has a biomass density of 672.80 Mg/ha or an equivalent of 305.50 Mg/ha of carbon. Implication of these results could be two things: (1) Carbon contained in forest lands can be restored when a degraded forests is rehabilitated and managed; and (2) Bringing back the original amount of carbon in the forest lands will take long period of time (≈80 years).

Table 10. Biomass and C density and MAI in Iloilo province, Philippines.

Species	Mean dbh (cm)	Biomass Mg/ha	MAI Biomass (Mg/ha/yr)	C density (Mg/ha)	C MAI (Mg/ha/yr)
Acacia neriifolia	17.53	87.13	21.78	39.21	9.80
A. holosericea	11.92	34.40	8.60	15.48	3.87
A. crassicarpa	18.91	155.79	38.95	70.11	17.53
A. aulacocarpa	12.99	56.36	14.09	25.36	6.34
Leucaena diversifolia	3.28	0.66	0.16	0.30	0.07
Casuarina cuminghiana	3.76	3.21	0.80	1.44	0.36
C. equisitifolia	7.77	15.55	3.89	7.00	1.75
Eucalyptus citrodora	12.14	52.41	13.10	23.58	5.90
E. cloeziana	11.61	48.27	12.07	21.72	5.43
E. pellita	10.36	33.99	8.50	15.30	3.82
E. tereticornis	11.76	49.87	12.47	22.44	5.61

DBH data from Lachica-Lustica (1997); age of trees= 4 years; biomass computed using the equation Biomass/tree in kg= 21.297 6.953*dbh+0.74dbh^2 for broadleaf species and for conifers Biomass/tree= EXP-1.17+ 2.119*LN(dbh) (from Brown 1997); %C in biomass= 45% (based on Lasco and Pulhin 2000)

Table 11. C density and MAI of reforestation areas 80 years after planting in Mt. Makiling, Philippines.

Species	Age (yrs)	Number	Biomass (Mg/ha)	Annual rate (Mg/ha/yr)	C density (Mg/ha)	MAI (Mg/ha/yr)
Swietenia macrophylla 1	80	802	564.92	7.06	254.21	3.18
Swietenia macrophylla 2	80	405	634.99	7.94	285.75	3.57
Parashorea malaanonan+ Anisoptera thurifera	80	569	536.12	6.70	241.25	3.02
Parashorea malaanonan+ Dipterocarpus grandiflorus	80	701	279.14	3.49	125.61	1.57

Note: age and dbh data from Sakurai *et al*., 1994; biomass computed using the equation Biomass/tree in kg= EXP{-2.134+2.53*LN(dbh)} (from Brown 1997); %C in biomass= 45% (based on Lasco and Pulhin 2000)

In Leyte, biomass values of trees were estimated through the use of destructive sampling. In this method, sample trees are harvested, weighed and oven dried. While this is quite an expensive and labor intensive method, it is the best way to estimate biomass. Results of the biomass estimation showed that *Gmelina arborea* had the highest biomass density among the three species studied. It contained 70.20 Mg/ha or an equivalent 31.59 Mg/ha of carbon in the biomass. *Acacia auriculiformis* which ranked second in terms of carbon accumulation had a biomass density of 63.50 Mg/ha or 28.58 MgC/ha while *Acacia mangium* had a biomass density of 56.90 Mg/ha or 25.61 MgC/ha (**Table 12**). Mean annual increment of the reforestation species range from 6.40 MgC/ha/yr to 7.90 MgC/ha/yr.

Silvicultural treatments, like fertilization, weeding and mycorrhizal inoculation, increase the growth of trees and consequently enhance the rate of C sequestration. In tree plantation sites Surigao del Sur, Philippines, the effect of mycorrhizal inoculation on carbon storage and accumulation were investigated. Results showed that inoculated trees plantation sites had higher biomass and carbon densities compared with uninoculated ones. A remarkable increase of 237% in the carbon stored and accumulated carbon were observed in *Eucalyptus deglupta* plantation that were given mycorrhizal treatment. About 136% increase was on the other hand noted in the *Pinus carribea* plantation while 32% increase was observed in another *Eucalyptus deglupta* plantation (**Table 13**).

Similarly, in tree plantations in Tarlac, mycorrhizal inoculation resulted to 43-169% increase in biomass and carbon density and carbon accumulation. Inoculated *Acacia auriculformis* had C density of 4.44 Mg/ha while uninoculated stand had 3.11 Mg/ha only. In the *Casuarina equisitifolia* stand, mycorrhizal inoculation caused an increase in biomass and C density and

Table 12. Biomass and C density and MAI in Leyte Philippines.

Species	Biomass (Mg/ha)	MAI Biomass (Mg/ha/yr)	C density (Mg/ha)	C MAI (Mg/ha/yr)
Acacia mangium	56.90	14.23	25.61	6.40
Gmelina arborea	70.20	17.55	31.59	7.90
A. auriculiformis	63.5	15.88	28.58	7.14

Biomass data from Buante (1997); % C in biomass assumed to be 45%
Age of trees= 4 years

Table 13. Effect of mycorrhizal inoculation C density and MAI of tree plantations in Surigao del Sur, Philippines.

Species/ Treatment	Age (yrs)	Diameter (cm)	Biomass (Mg/ha)	MAI Biomass (Mg/ha/yr)	C density (MgC/ha)	C MAI (MgC/ha/yr)
Pinus Caribbea						
Uninoc	2	6.11	15.97	7.98	7.18	3.59
Inoc	2	9.17	37.74	18.87	16.98	8.49
		% Difference	136			
Eucalyptus deglupta						
Uninoc	2	4.15	5.76	2.88	2.59	1.30
Inoc	2	6.3	7.63	3.81	3.43	1.72
		% Difference	32			
Eucalyptus deglupta						
Uninoc	3	9.435	23.96	7.99	10.78	3.59
Inoc	3	14.26	80.69	26.90	36.31	12.10
		% Difference	237			

Diameter data from dela Cruz (1999); No of trees= 1111/ha
Allometric equation for *P. caribaea*: Y (kg)= exp{-1.170+2.119*ln(D)} range 2-52cm; for E. deglupta: Y (kg)= Y (kg)= 21.297-6.953(D)+0.740(D^2) (Brown 1997)

C accumulation by as much as 169%. Inoculated stand of *Casuarina equisitifolia* had biomass density of 7.58 Mg/ha and C density of 3.41 Mg/ha. Carbon accumulation was found to be at the rate of 1.71 MgC/ha/yr (**Table 14**).

While the range of increase in carbon density and accumulation is quite wide, results of the study showed that mycorrhizal inoculation provides a promising way to enhance carbon storage and carbon accumulation of trees.

Table 14. Effect of mycorrhizal inoculation C density and MAI of tree plantations in Tarlac, Philippines.

Species/ Treatment	Age (yrs)	Diameter (cm)	Biomass (Mg/ha)	MAI Biomass (Mg/ha/yr)	C density (MgC/ha)	C MAI (MgC/ha/yr)
Acacia auriculiformis						
Uninoc	2	6	6.91	3.45	3.11	1.55
Inoc	2	7	9.87	4.94	4.44	2.22
		% Difference		43		
Casuarina equisitifolia						
Uninoc	2	2.7	2.83	1.41	1.27	0.64
Inoc	2	4.3	7.58	3.79	3.41	1.71
		% Difference		169		

Allometric equation for *C. equisitifolia*: Y (kg)= exp{-1.170+2.119*ln(D)} range 2-52cm; adj r2=0.98 (Brown 1997)
Allometric equation for *A.auriculiformis*: Y (kg)= 21.297-6.953(D)+0.740(D^2) range 4-112cm; adj r2=0.92 (Brown 1997)

CONCLUSIONS AND RECOMMENDATIONS

The preceding review of the effects of LUCF activities on carbon budgets in the Philippines revealed the following conclusions:

- C density in AGB declines by at about 50% after logging.
- Deforested areas covered with grasses and annual crops have C density less than 15 MgC/ha.
- Conversion of natural forests to tree plantations and perennial crops reduce C density by about 50%.
- Reforestation activities in degraded areas increase C density with a mean annual accumulation of up to about 10 MgC/ha/yr for fast growing species and 3 MgC/ha/yr for slow growing species.
- Silvicultural treatments such as mycorrhizal inoculation can increase C accumulation.

While much data has been generated in the last few years in the Philippines, there are still wide gaps in our knowledge of the effects of LUCF activities on carbon budgets. The following research areas need to be given attention.

- Generation of country-specific allometric equation- The Philippines still rely on allometric equation developed from other countries.
- C stocks assessment of forest ecosystems- While some information have been gathered recently, these are still very few relative to The vast areas and varied conditions in the Philippines.
- Development of cost-effective and accurate methods to assess various forest ecosystems. We have tested the use of plotless techniques which may provide more accurate estimate than small plot techniques.

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