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Carbon Stock and Net CO_2 Emission in Tropical Upland Soils under Different Land Use

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ABSTRACT

Carbon storage and CO_2 emissions were measured during May 2003-February 2004 in three land use types in northeastern Thailand. These included a natural dry evergreen forest (DEF), a reforestation planted with 16-years old *Acacia mangium* (AC) and a cornfield site (CF). The main objective was to estimate and compare carbon stock as affected by land use type. On the area-basis, the estimated of carbon storages in the upper 50 cm-layer of soil were 118, 66 and 57 ton C ha^{-1} in DEF, AC and CF soils, respectively. The total carbon storages (standing biomass plus soil carbon, excluding belowground biomass) were 418, 164 and 60 ton C ha^{-1} in DEF, AC and CF soils, respectively. At forest site, majority of carbon was stored in the standing biomass (71% and 60% of total carbon storage at DEF and AC site, respectively). At CF site, however, about 95% of carbon was stored in the soil. Total net CO_2 emission was not significantly different among these three sites (12-17 ton C ha^{-1} yr^{-1}), presumably due to large spatial and temporal variations. The results indicated that the amount and characteristics of carbon storage differed significantly depending on land use type. Conversion of natural forest to agriculture (after 16 years), in addition to loss of carbon stored in the standing biomass, might result in about 50% loss of soil carbon in the upper 50 cm. On the other hand, reforestation for 16 years might increased soil carbon by 14% (0.6 ton C yr^{-1}) compared with a continuous cultivated soil (maize).

Key words: carbon stock, land use, natural forest, reforestation, corn cultivation

INTRODUCTION

Concentrations of atmospheric carbon dioxide (CO_2) have increased from around 285 ppmv (part per million by volume) during pre-industrial time (ca.1750) to about 377 ppmv in 2003 (Keeling and Whorf, 2004), increasing at approximately 1.5 ppm yr^{-1}. This has increased CO_2 radiative forcing to approximately 1.6 W m^{-2} compared to its effect in 1750 (IPCC, 2001). The major contributions to this increase have been anthropogenic consumption of fossil fuels and deforestation.

In the terrestrial ecosystem, forests (live and dead trees, and soils) globally contain the largest stocks of organic carbon (2300 PgC (1 Pg = 10^{15} g), IPCC, 2001). Land use changes, for example, conversion of natural forest to agriculture, release this large amount of carbon stored in plants and soils to the atmosphere. During

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the past decades, the most remarkable change in land use has been deforestation in the tropics. The net release of CO_2 from tropical deforestation was estimated in the range of 0.1–1.4 PgC yr^{-1} for the 1990s (DeFries *et al*., 2002; Achard *et al*., 2002). This flux represents a large portion of global carbon budget and may contribute significantly to an increasing atmospheric CO_2 concentration as currently observed (IPCC, 2001).

Forest re-growth is one of the options that can help sequester carbon in the ecosystem and thus slow down the recent atmospheric increase. However, the magnitude and rate of carbon sequestration are poorly known, and depend on many factors such as forest plantation management, soil characteristics, soil erosion and forest species (De Camargo *et al*., 1999; Paul et al., 2002). Carbon dynamics in the tropics and its disturbances, therefore, have great potential to affect the global carbon balance. Understanding the underlying processes of uptake and release of carbon in the tropical ecosystems must be established if it is to predict the future trends of global CO_2 in the atmosphere and to mitigate CO_2 emission from the regions.

Change in land use and land use type significantly affects soil characteristics and soil carbon content (Paul *et al*., 2002; Dunjo *et al*., 2003). Agricultural practices such plowing usually accelerates soil decomposition and reduces soil carbon content (Franzluebbers, 2005; Tan and Lal, 2005). On the other hand, manure fertilization and reduced tillage or no-till have been demonstrated to increase both soil carbon and fertility (Wright and Hons, 2005). Characterizing land use type and its carbon storage capacity, therefore, is crucial to improve the understanding of both regional and carbon dynamics.

In this study, a comparative study on soil carbon stock and CO_2 emissiond in different land use types was conducted. The main objectives were to estimate carbon stock (soil and above ground) under different land uses, and to know the potential gain of ecosystem carbon when forest was re-grown on the formerly disturbed land.

MATERIALS AND METHODS

Study site

This study was carried out in three adjacent sampling sites located in Wang Nam Kaew District, Nakhon Ratchasima province in Northeast Thailand. The forest site was a natural dry evergreen forest (DEF) located within the Sakaerat Environmental Research Station. The average annual temperature at the sites was 26°C and the average annual rainfall was 1,260 mm. The dominant tree species were *Hopea ferrea*, *Pterocarpus marcrocarpus*, *Xylia xylocarpar*, *Dalbergia cochinchinensis*, *Lagerstroemia duppereana*, and *Shorea henryana*. The reforestation site (AC) was located about 5 km northwest of the DEF site was planted with a fast-growing, nitrogen-fixing tree species *Acacia mangium* in 1988. The third sampling site was a cornfield (CF), situated adjacent to the reforestation area (3 km away). It was deforested more than 40 years ago and maize had been continuously cultivated at this site during the last 16 years since 1988. Soil preparation for corn plantation at the CF site started in the mid of June, 2003 and seeds of corn were sown on July 10, 2003. On this date, chemical fertilizer (16-20-0, N-P_2O_5-K_2O) was applied at the rate of 25 kg ha^{-1}.

Soil sampling

Soil cores with a diameter of 5 cm were used to collect soil samples. Twenty-one cores were sampled at each location. Three replicates per soil layer from a total of seven soil layers were collected (0-5, 5-10, 10-15, 15-20, 20-30, 30-40 and 40-50 cm). In the laboratory, soil samples were air-dried, sieved through 2-mm mesh and stored at room temperature until analysis. Undisturbed soil samples were taken separately to measure bulk density.

Soil analysis

The soil texture was determined by using hydrometer method (Bouyoucous Particle Size Analysis) on air-dried soils that were passed through a 2-mm sieve to remove small rock, roots, pebbles and debris, followed by wet sieving to separate sand function. Sand, silt, and clay were expressed as a percentage of oven-dry weight basis (Gee and Bauder, 1982). Bulk density was determined by measurement of volume and weight after oven-dry at 105 °C until reaching a constant weight (Blake and Hartge, 1986).

Determination of carbon content in soil and biomass

The total carbon (organic and inorganic carbon) was analyzed by using an elemental analyzer (FlashEA 1112, Italy). This analytical method quantitatively determined the total amount of nitrogen and carbon in all forms in the soil using a dynamic flash combustion system coupled with a gas chromatographic (GC) separation system with flame ionization detector (Verardo *et al*., 1990). The amount of soil carbon stock was estimated by using the following equation;

Soio carbon stock (gC/m^2) = Bulk density (gsoil/m^3) × soil carbon content (gC/g soil) × depth (m)

Secondary data sources were collected to obtain the yearly input of carbon at all sites. These mainly included total aboveground biomass at DEF site studied by Wachrinrat and Takeda (in press) over 1998-2001 and total aboveground biomass and carbon content in *A. mangium* plantation by Visaratana *et al*. (2004) at Re-afforestation Research and Training Station. These data sets were used to calculate the carbon input into the soil as litter fall. The calculation of carbon content from the tree biomass applied the conversion factor of 0.5 as described by Brown *et al*. (1991). Estimation of corn biomass after harvest was carried out at the end of 2003 growing season. Corn residues were randomly collected. One square meter of iron frame was placed randomly through out the plots and all of residues contained within this frame were collected. After collection, residues were washed by distilled water to remove any soil residual and dust, placed in a paper bag and dried at 85°C for 24 hours. After drying, corn residues were weighed. The amount of carbon input into the plot was estimated by multiplying the weight of corn biomass with carbon content (44% on dry weight basis), assuming that all the residues were eventually incorporated into the soil during the next field preparation period.

Soil CO_2 flux measurement

Field CO_2 measurements were carried out at these three sites during May 2003 - February 2004. The CO_2 flux was measured by using a closed chamber method (Knief *et al*., 2005). Chambers were made of acrylic glass with the dimensions of 30 cm × 30 cm × 15 cm (width × length x height) and chamber base; 30 × 30 × 10 cm^3. The internal volume of the chamber was approximately 13,500 cm^3. The chamber base was made of stainless steel and custom constructed with an upper trough that exactly fitted the base of the chamber. They were inserted into the sampling location at 10-15-cm deep into the soil and remained in the same proximal and distal locations during the entire study period. The number of chambers used at each site were 10, 5, and 5 for DEF, AC and CF sites, respectively.

Gas samples (20 mL) from the chamber headspace were taken at 0, 5, 10, and 15 minutes with a gas syringe through a top three-way stopcock. Together with gas collection, other environment parameters such as soil and air temperatures were also recorded. After sampling, the gas samples were kept in a cool box to maintain the stable temperature. Upon returning to the lab, the concentration of CO_2 was determined by a gas chromatograph equipped with methanizer within 24 hr (Shimadzu GC-14A). The GC operating conditions were; FID temperature: 300°C, injection temperature: 120°C, column temperature:

100°C, carrier gas: Helium (99.99% purity), carrier gas flow rate: 65 mL min^{-1}, column: Unibead C packed column.

Data analysis

Statistical analysis was applied by using Analysis of Variance (ANOVA), reported at the confidence level of 95% ($p \leq 0.05$).

RESULTS AND DISCUSSION

Soil characteristics under different land use types

A basic assumption in this comparative study of carbon stock in different land uses was that initially the soils were similar in each study site. Choosing the study sites within the proximal vicinity to each other was one of the strategies to minimize the basic differences among sites. Before taking the samples, soil profile description was made at these sites (data not shown). Field observation revealed that soils at both forest (DEF) and reforested (AC) sites were similar to each other (as described in details below). However, soil at CF site somehow differed from both forest sites. At CF site the soil horizon was more than 1-m depth while at both DEF and AC this was about 50-70 cm. Such difference might result from long history of agricultural practice at CF site (>40 years). Some soil characteristics are described in Table 1 and explained as follows.

Bulk density

At all sites, bulk density increased with depth. Although on the average throughout the profile bulk density among the sites was not significantly different, there was the overall relatively higher value in CF site than that of DEF and AC sites. This was probably due to agricultural activity such as use of mechanical plowing, fertilization and weed management at the CF sites that resulted in increase soil compactness. The bulk density ranges were from 1.46 to 2.01, 1.56 to 2.04 and 1.62 to 1.94 g cm^{-3} at the DEF, AC and CF sites, respectively. From the field observation, there was also higher amount of gravel in the soil profile of the natural forest (DEF) and the reforestation area (AC), especially in the deeper profile layer than that in the CF soil.

Soil pH

The profile-average pH value of CF soil was statistically higher at approximately one pH unit than that of forest and reforest soils. The pH changes associated with changing from forest to agriculture was possibly attributed to liming and field burning. In natural forest (DEF site) and reforestation (AC site), the surface soils were strongly acidic with pH of about 3.86 and 3.98, respectively. It is known that forest soil pH is regulated by several factors such as mineralogy, plant types and decomposition of organic matter (Boruvka *et al.*, 2005). The major organic matter input in forest and reforest soils are from litter fall. Decomposition of such materials leaves in the soil certain acidic groups such as carboxyl group, phenolic group and amino group. Protonation of these functional groups releases hydrogen ion (exchangeable H^+) into the soils. Thus, high organic matter content usually associates with relatively acidic pH. In addition, acidic pH at forest sites could be due to growth characteristics of forest species. For example, Jongsuksuntigool and Tantiraphan (1994) found that *Acacia mangium* plantation soil (6 years old) was strongly acidic. This was attributed to active uptake of base elements such as potassium, calcium, and magnesium associated with its fast growing, resulting in abundance of free H^+ ions left in the soils.

Soil particle distribution and soil texture

A distinct distribution characteristic of soil particle was observed among the three study sites. DEF soil had the highest proportion of clay particle, while silt and sand fractions dominated particle distribution in the AC and CF soils, respectively. This gave the clayey texture for DEF

Table 1 Some characteristics of soils taken from different depth of the three land use types (mean ± SD). Means designated with the different letters denote a significant difference ($p<0.05$) among DEF, AC and CF sites.

Site	Soil depth (cm)	Bulk density	pH (H_2O) ($g\ cm^{-3}$)	Partic.le size distribution (%)			Soil texture
				Sand	Silt	Clay	
Natural forest (DEF)	0-5	1.57±0.20	3.86±0.02	49.56	15.00	35.44	Sandy clay
	5-10	1.46±0.09	3.90±0.02	42.56	15.00	42.44	Clay
	10-15	1.61±0.11	4.00±0.07	37.98	14.58	47.44	Clay
	15-20	2.01±0.27	4.28±0.02	32.98	13.94	53.08	Clay
	20-30	1.71±0.02	4.32±0.09	32.56	10.36	57.08	Clay
	30-40	1.83±0.17	4.35±0.06	28.56	11.36	60.08	Clay
	40-50	1.67±0.09	4.39±0.05	30.56	9.36	60.08	Clay\
	Average	**1.69±0.18^a**	**4.16±0.23^a**	**36.39±7.48^a**	**12.80?±2.38^a**	**50.81±9.43^a**	
Reforestation (AC)	0-5	1.56±0.07	3.98±0.03	54.56	22.36	23.08	Sandy clay loam
	5-10	1.60±0.07	4.08±0.01	50.56	23.00	26.44	Sandy clay loam
	10-15	1.57±0.04	4.15?±0.01	50.92	20.64	28.44	Sandy clay loam
	15-20	1.59±0.06	4.20±0.02	48.56	20.00	31.44	Sandy clay loam
	20-30	1.88±0.11	4.26±0.02	40.56	19.00	40.44	Sandy clay loam
	30-40	1.76±0.06	4.23±0.03	39.56	16.00	44.44	Clay
	40-50	2.04±0.40	4.27±0.03	46.92	13.64	39.44	Clay
	Average	**1.71±0.19^a**	**4.17±0.10^a**	**47.38±5.53^b**	**19.23±3.37 ^{b}**	**33.39±8.08 ^{b}**	
Agriculture (CF)	0-5	1.62±0.12	5.02±0.14	72.56	8.00	19.44	Sandy loam
	5-10	1.79±0.10	5.16±0.00	70.56	10.00	19.44	Sandy loam
	10-15	1.88±0.05	5.21±0.02	69.20	9.36	21.44	Sandy clay loam
	15-20	1.86±0.03	5.31±0.04	68.98	9.58	21.44	Sandy clay loam
	20-30	1.96±0.21	5.59±0.04	70.20	8.36	21.44	Sandy clay loam
	30-40	1.93±0.02	5.80±0.06	68.84	9.72	21.44	Sandy clay loam
	40-50	1.94±0.03	5.94±0.04	68.20	10.36	21.44	Sandy clay loam
	Average	**1.85±0.12^a**	**5.43±0.35^b**	**69.79±1.46^c**	**9.34±1.46^c**	**20.87±0.98^c**	

soil while in other sites the soil texture was sandy clay loam to sandy loam. Thus, soil under agriculture was sandier than soil under reforest and natural forest. These results agreed with Phopinit and Limtrakul (1999), who found that soil particle compositions after reforestation of 10 years. changed towards the sandier soil texture. Agricultural practices such plowing that mixed the topsoil with subsoil and a subsequent leaching of clay particles from surface to subsoil by rainfall were suggested as the possible reasons making the surface soil rich in sand particle.

Total soil carbon and nitrogen under different land use

Land use greatly influences carbon dynamics in soil. Forest ecosystem generally stores large amount of carbon (above- and below-ground biomass and soil organic carbon). Conversion of natural forest to agriculture results in loss of such stored carbon. However, the magnitude and rate of loss depends upon the method of forest conversion, the intensity of subsequent land use, the climate, and the soil physical and chemical properties (Fernandes *et al*., 1997). In this study, the total soil carbon and nitrogen were measured along the soil depth up to 50 cm (Figure 1). In all land use types examined, the highest carbon content was found in the topsoil. The carbon content was usually highest in the DEF soil, ranging from 15 mg C g soil^{-1} in subsoil to 30 mg C g soil^{-1} in the top 10-cm soil, followed by soil at AC site (10-15 mg C g soil^{-1}) and CF soil (<10 mg C g soil^{-1}), respectively.

Similar tendencies were also found for the nitrogen content, but about 10 times in magnitude less than that for carbon content (Figure 1B). The total N content was more than 1.5 mg N g soil^{-1} in the top 10 cm in the DEF soil while this was generally less than 1 mg N g soil^{-1} in the AC and CF soil. The level of soil N in AC and CF was not different. In all soils, the N content decreased when soil depth increased. The C:N ration in all soil narrowly ranged between 10 and 11.

By multiplying the carbon or nitrogen content with the bulk density in each soil layer, carbon and nitrogen storage in each land use type was estimated. The total carbon stocks for 50-cm soil depth were 118, 66, and 57 ton C ha^{-1} in the DEF, AC and CF soils, respectively. Approximately 51, 46 and 51% of this total carbon were stored in the top 20 cm of soil at the DEF, AC and CF sites, respectively. This calculation results indicated that natural forest, besides storing large amount of carbon in plant biomass, stored more carbon in soil than in other land use types. Conversion of forest to agriculture in this case, therefore, could result in a substantial loss of soil carbon. On the other hand, reforestation to *Acacia mangium* for 16 years could result in increasing soil carbon storage (10 ton C ha^{-1} over 16 years, compared to the CF soil). Thus, it could be said that the main carbon sequestration at ecosystem level could be achieved mainly through an increase in the standing plant biomass. The total nitrogen storages in the DEF, AC and CF soils were 10, 6.5 and 5 ton N ha^{-1}, respectively. Similar to carbon storage, about 50% of the total nitrogen in the soil profile was found in the top 20 cm soil layer.

The simple regression analysis of relationship between soil carbon or nitrogen contents and other soil properties revealed that carbon content did not correlate with any soil physical or chemical properties (pH and soil texture). However, soil carbon content significantly correlated with nitrogen content (Soil C content = 12.2{soil N content} – 1.14, $r^2 = 0.92$, n = 21, $p<0.0001$). This was expected, since these two shared the same input sources (litter fall). However, it might also indicate that higher N input into the system would likely increase the amount of carbon storage and sequestration.

Carbon stocks in biomass and litter fall

The amount and quality of litter is one of the important factors that determine how much carbon could be preserved in soil. Low rate of litter fall, decomposition and incorporation into the mineral soil leads to low soil carbon content. The amount of litter production varies from biome to biome. Factors that affect litter fall include plant species, environment, silvicultural practices, and time factor. Generally, plantation yields more litter fall than the natural stand. This was attributed to the even-aged condition of plantation rather than stand density (Thaiutsa *et al.*, 1978).

The most relevant study on litter production at DEF site used to estimate the carbon input in this study was given by Watchrinrat and Takeda (in press), who studied the litter fall pattern

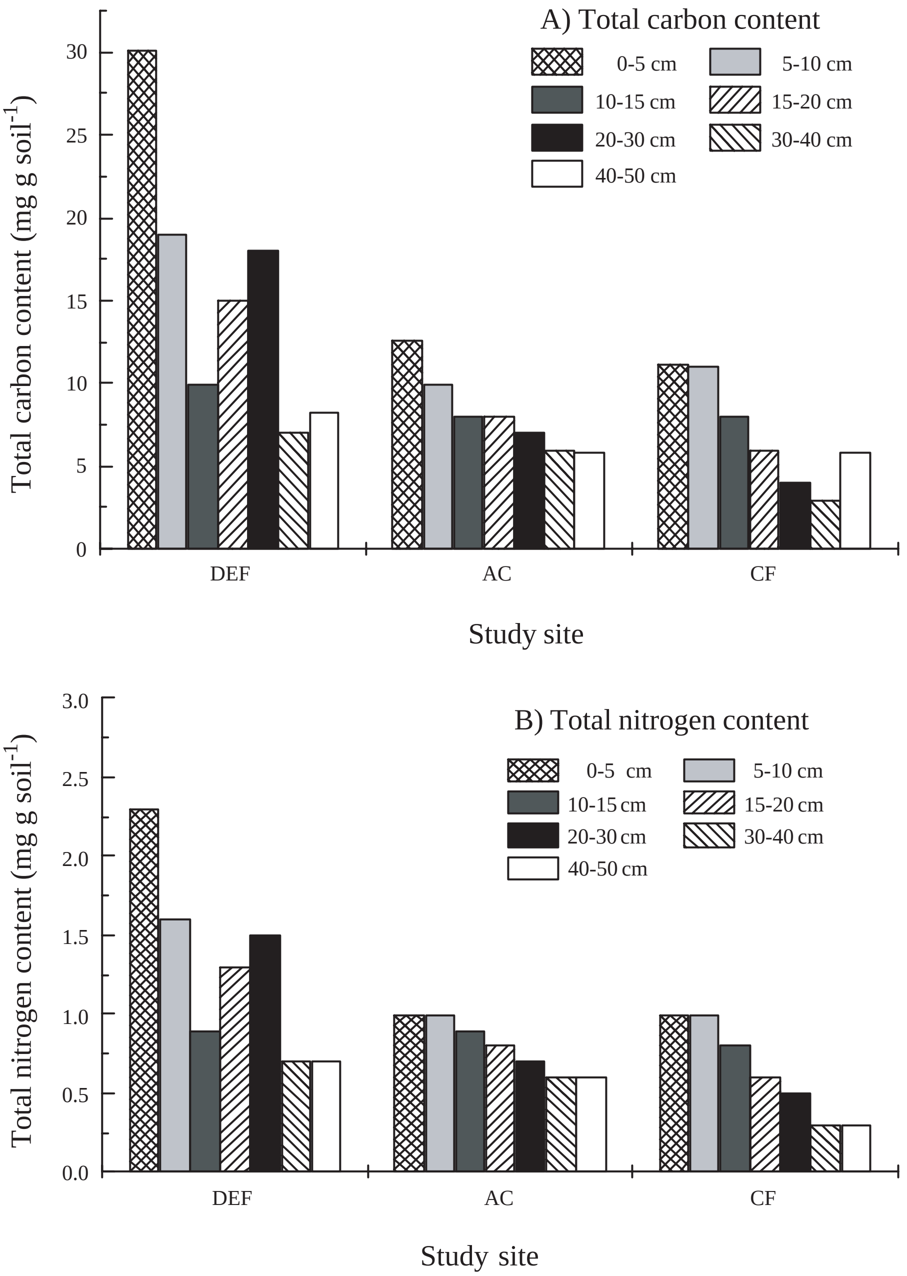

Figure 1 Total soil carbon and nitrogen contents as a function of soil depth in different land use types: A) total carbon content and B) total nitrogen content.

at DEF site during January 1998 to December 2000. The results indicated that there were clear relationships between season and total litter fall. The large portion of litter production was found during rainy season (62 ± 11% of total litter fall). The total litter fall was estimated at 7.81 ton ha^{-1} yr^{-1}. Other previous studies also showed the similar ranges, from 7.7 to 8.2 ton $ha^{-1}year^{-1}$ (Table 2). In this study the adopted value of 7.82 (equivalent to 3.91 ton C yr^{-1}) which was the average litter fall from all available literature shown in Table 2.

For the AC site, Visaratana *et al.* (2004) studied the total litter fall production in the same plots as used in this study during 2003. Thus, their value was directly adopted, which was 15.52 ton ha^{-1} (equivalent to 7.76 ton C yr^{-1}). It was noted that during their 2 years study, there was a significant higher litter fall in 2003 than in 2002 (about 36% higher). They attributed this unusual high litter fall to the relative higher precipitation in 2003 than 2002 (about 1.6 times, Table 2).

For the CF site, the total amount of maize residue left after harvest was measured. The value obtained was 5.90±1.39 (n = 3) ton ha^{-1} yr^{-1} for 2003 growing season. Because there was no field burning at this site, this fraction of maize residue was assumed to be incorporated into the soil and attributed to the soil carbon and the CO_2 emission in the subsequent cropping.

Net CO_2 flux from soil surface

The monthly average soil CO_2 fluxes from May 2003 to February 2004 are shown in Figure 2. At all sites, soil CO_2 flux was high during July-November, which was the rainy season at the sites. Changes in CO_2 emission generally followed the pattern of soil moisture content measured at 6 cm, indicating that soil moisture content was one

Table 2 Data compiled on litter fall production in dry evergreen forest (DEF) and reforestation used in this study, RTRS = Research and Training in Re-afforestation Station, Nakhon Ratchasima.

Forest types	Site	Annual rainfall (mm)	Total litter fall (ton ha^{-1} yr^{-1})	Reference
DEF	Sakaerat Nakhon Ratchasima	ND*	7.71	Chunkao and Boonyawat (1980)
DEF	Sakaerat, Nakhon Ratchasima	ND	8.17	Chinsukjaiprasert (1994)
DEF	Khoa Ang Ru Nai Wildlife Sanctuary, Chachoengsao	1,883	9.01	Thanee (1998)
Secondary DEF	Khoa Ang Ru Nai Wildlife Sanctuary, Chachoengsao	1,883	8.04	Thanee (1998)
DEF	Sakaerat, Nakhon Ratchasima (Year 1998-2001)	1,240	7.81	Wachrinrat and Takeda (in press)
Acacia mangium, 16 and 17 years old	RTRS, Nakhon Ratchasima	1,588.7 (in 2002) 2,483.8 (in 2003)	9.93 (in 2002) 15.52 (in 2003)	Visaratana *et al*. (2004)

*ND= not data.

of the important factors controlling CO_2 exchange at soil surface. In both forest soils, a clear relationship between soil CO_2 flux and moisture was not obtained. However, a significant correlation between soil moisture at 6 cm and CO_2 flux was observed at the CF site ($r^2 = 0.71$, n = 8). This indicated that in forest soils, factors other than soil moisture might play an important role. Certain roles of plant canopy and root respiration and their response to moisture might also influence soil respiration. This suggested that soil respiration varies spatially, depending on local factors that were quite specific to each site and location.

Soil CO_2 fluxes in the natural forest, reforestation and corn cultivation sites were in the ranges from 0.00 to 0.96, 0.10 to 0.99 and 0.08 to 0.94 kg CO_2 m^{-2} $month^{-1}$, respectively. The increase in soil CO_2 emission was also found when there was high litter production. Thus, besides the moisture content of soil, the input of organic material through litter fall was likely another factor affecting soil CO_2 emission.

Based on the data during 8 months, accumulated CO_2 emission was estimated and normalized to one year period (Table 3). The total CO_2 emission ranged from about 10.2 ton C ha^{-1} at DEF site to about 14.6 ton C ha^{-1} at AC site. No significant difference among site in CO_2 emission was observed. This was possibly due to large variations associated with flux, which were more than 50% of the means at all sites. However, the total CO_2 emission from AC soil was the highest among these three sites, agreeing with its highest rate of litter fall as mentioned above.

Summary of carbon stock and releases as CO_2

The amount of soil carbon at a given time is determined by the carbon inputs, outputs and factors which regulates these processes. Carbon input and release as CO_2 in different land uses is illustrated in Figure 3. In 2003, litter fall at the AC site was highest, followed by at the DEF and CF sties, respectively. Similarly, the highest CO_2 emission was found at the AC site. The total carbon stocks (excluding below biomass which is normally about 30% of above ground biomass) were 418, 164 and 60 ton C ha^{-1} for DEF, AC and CF sites, respectively. More than 71% and 60% of this carbon in DEF and AC sites were found in plant biomass and the rest were stored as soil

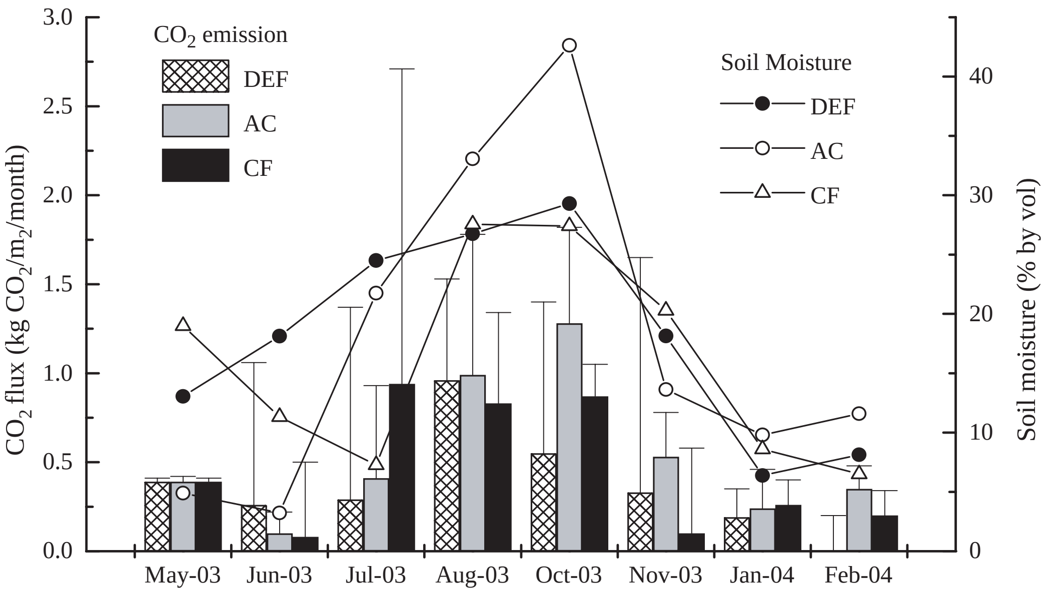

Figure 2 Net soil CO_2 flux and soil water content during May 2003-February 2004.

carbon. Thus, plant biomass was important as the main reservoir for carbon storage in these ecosystems. In contrast, majority of carbon at CF site was found in the soil (>90%). Any measures that result in preserving soil organic Carbon, thus, will help increase agricultural ecosystem to sequester carbon and to reduce net CO_2 release to the atmosphere.

It was noted that the amount of carbon release as CO_2 exceeded the amount of carbon

Table 3 Effect of land use type on averaged CO_2 emission during 8 months (mean ± S.D, N = 8 months). Means designated with the different letters denote a significant difference ($p<0.05$) among DEF, AC and CF sites.

Land use type	Total soil CO_2 emission ($kg\ CO_2 \bullet m^{-2} \bullet 8\ months^{-1}$)	Carbon equivalent normalized to one year ($ton\ C\ ha^{-1}\ y^{-1}$)
Dry evergreen forest (DEF)	2.98 ± 5.00	10.16^{a}
Reforestation (AC)	4.28 ± 2.60	14.56^{a}
Corn cultivation (CF)	3.66 ± 3.67	12.46^{a}

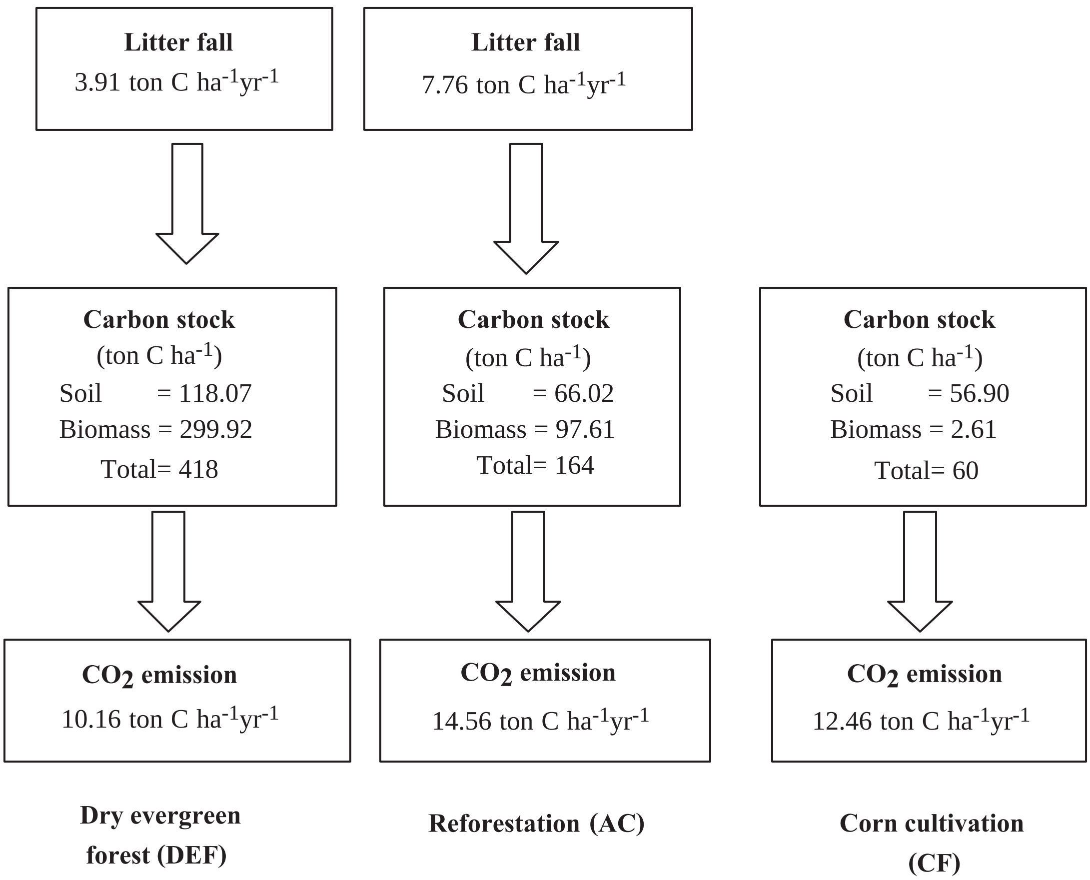

Figure 3 Summary of carbon inputs and emission as CO_2 in different land uses. Noted that the amount of the standing plant biomass in dry evergreen forest was obtained from that reported in Sahunalu *et al*., 1993, and in reforestation area was obtained from Nualngam, 2002.

inputs as litter fall in case of DEF and AC sites or residue was left on the field after harvest in case of CF site. At DEF and AC sites, this might be caused by the contribution of CO_2 released from plant root respiration. Researches in the past have shown that root respiration can make up the majority of soil CO_2 fluxes. For example, Raich and Tufekcioglu (2000) reported that root contribution to soil respiration was 33–89% in forests. Such respired carbon is supplied by a direct translocation of photosynthate from leaves to roots. On the other hand, large flux of CO_2 in agricultural soil (CF site) may be explained by active decomposition of organic matter in soil. Thus, even after many years of land conversion from natural forest to agricultural land, equilibrium (input ≅ output) in carbon dynamics has not yet been attained in agricultural soil. Such may result in a reduced carbon content in the soil from agricultural area as observed in the present study.

Assuming that the level of carbon stored in the soil at the beginning was similar among these land use types, carbon loss and gain upon land use change could be roughly estimated. Direct conversion of natural forest to agricultural land resulted in loss of more than 90% of carbon in aboveground biomass. More than 50% of soil carbon was also reduced in this case. On the other hand, besides achieving carbon gain in plant biomass forest plantation for 16 years has restored soil carbon of about 10 ton C (a net gain of 0.57 ton C ha^{-1} yr^{-1}).

CONCLUSIONS

This study showed that carbon stock differed significantly depending on land use types. The highest carbon stock was found in the natural forest, followed by the forest plantation and agriculture area, respectively. At all sites, more than 50% of total soil carbon and nitrogen was found in the upper 20 cm. In this case, ecosystem carbon storage at forest site was more than sevenfold higher than that of carbon storage at agricultural site. Thus, ecosystem disturbances, such as conversion of forest to agriculture, would likely lead to a substantial loss of ecosystem carbon storage and sequestration. In addition, these results indicated that forest plantation could help increasing carbon storage through plant growth as well as accumulation of organic carbon in soil.

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