

Soil Carbon Dioxide Efflux under Different Canopy Densities of Ayer Hitam Forest in Malaysia

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ABSTRACT

Soil Carbon Dioxide (CO₂) efflux has been identified as a crucial component of the forest carbon balance. It is essential to comprehend soil CO₂ efflux in various stand densities and carbon cycles. The aim of this paper was to determine the influence of environmental and biological factors on soil CO₂ efflux under different forest canopy densities. Field survey was carried out between the months of November and December (monsoon period). Measurements of soil CO₂ effluxes were conducted using a continuous open flow chamber technique. The selection of the experimental plots used was based on stand density. Three compartments based on Leaf Area Index (LAI) of dense, open and moderate canopy sites were sampled and studied. The impact of environmental variables and biological activities on soil CO₂ efflux was determined using the multiple linear regression model. The findings show that soil CO₂ effluxes ranged from 256.03-1038.82 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ ($P<0.001$), 118.83-1129.40 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ ($P<0.001$) and 275.38-1840.50 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ ($P<0.001$) in dense, open and moderate canopies respectively, with the highest CO₂ emission from the moderate forest canopy. The beta coefficients of soil moisture and soil temperature were high with 132.927 and 29.641 ($P<0.024$), in the dense forest canopy, -670.383 and 109.477 ($P<0.024$), in the open canopy and 714.097 and 26.741 ($P<0.024$) in the moderate forest canopy. Generally, high soil moisture and soil temperature signify the most influential factors controlling soil CO₂ efflux. It is concluded that soil organic carbon (SOC), total organic carbon (TOC), litter fall carbon and nitrogen (C&N), soil moisture content and porosity (bulk density) account for the spatial and temporal variation in soil CO₂ effluxes as predicting variables.

Keywords: Canopy density, Leaf Area Index, Litter fall, Soil CO₂ efflux.

1. INTRODUCTION

Global climatic change is a result of the increase in greenhouse gases contributed by the terrestrial carbon budget (Schlesinger and Andrew, 2000; Dufresne *et al.*, 2002). Whereas global warming can trigger soil CO₂ efflux into the atmosphere to compensate the carbon uptake by photosynthesis (Piao *et al.*, 2005) which is a result of the high amount of

carbon in the soil of the terrestrial ecosystem (Dupouey *et al.*, 1999; Luyssaert *et al.*, 2010), any change in the environmental variability will affect the autotrophic and heterotrophic respiration by roots and soil organisms, thereby increasing the soil CO₂ efflux (Pangle and Seiler, 2002; Gough and Seiler, 2004; Luo and Zhou, 2006).

Soil CO₂ efflux has been recognised as a major factor for climate change. Therefore, evaluating the capacity of forest ecosystems in different stand canopy densities, tree species, age and forest management activities is paramount. In addition, assessing their contributing impact on the atmospheric carbon balance influences global climate change and predicting future occurrences is vital (Lee and Jose, 2003; Pypker and Fredeen, 2003; Wang *et al.*, 2006). Litton *et al.* (2003) and Kim *et al.*, (2009) reported that the mismanagement of forest resources through human activities such as deforestation, thinning, land use and fire, have increased soil CO₂ efflux, which is found to be related to the succession in *Dipterocarp* forest canopy density of the Ayer-Hitam forest Peninsular, Malaysia. The forest ecosystem has been recognised as a sink for CO₂ because of its high productivity, which is a good climate change mitigation measure (Goodale *et al.*, 2002; Nabuurs *et al.*, 2003). A study of carbon dynamics under different forest canopy densities is paramount in understanding global carbon cycles (Linderner and Karjalainen, 2007; Jandl *et al.*, 2007).

The determination of soil CO₂ efflux in relation to major environmental factors is paramount in ascertaining the controlling factors and the corresponding CO₂ efflux from the soil via the forest into the atmosphere. This process can be used to calculate the percentage of CO₂ emitting into the atmospheric carbon pool, notwithstanding that there are challenges in estimating the soil CO₂ efflux and its percentages into the atmosphere because of the spatial heterogeneity and temporal variability of the carbon stock as it is linked to the dynamic carbon stock in the soil (Schimel, 1995; WBGU, 1998; IPCC, 2000). Although various studies have examined soil respiration and environmental factors under different climatic and vegetation conditions

using different techniques (Hibbard *et al.*, 2005; Davidson and Janssens, 2006), there is much to be explored in the converted and logged tropical rainforest ecosystem in terms of soil CO₂ efflux. Although, Lulie *et al.* (2005), Wan *et al.* (2003), Adachi (2005) and Rahman *et al.* (2005) reported that the 30-year old succession *Depterocarp* forest is under threat from further logging in years to come, studies on soil respiration and related factors are limited. The soil CO₂ efflux of the tropical rainforest is an important issue at both regional and global scales. Thus, this study aimed at an assessment of soil CO₂ efflux under different forest canopy densities of Ayer Hitam Forest in Malaysia. The specific objectives of the study were to determine the influence of environmental factors on soil CO₂ efflux under different forest canopy densities in the tropical rainforest ecosystem and estimate the rate, spatial and temporal variation in soil CO₂ efflux across the different forest canopy stand densities.

2. MATERIALS AND METHODS

2.1 Study Area

The Ayer Hitam Forest, Malaysia (that is *Depterocarp* forest reserve) is located between 3° 00' to 3° 22' N and 101° 37.9' to 101° 40.0' E (Figure 1). It has a land mass of 1,248 hectares, and is located 15-233m above sea level, with a slope slant of 10-20%. The reserve is a research and extension forest for Universiti Putra Malaysia. The study area is approximately 45km from Kuala Lumpur (Paiman *et al.*, 2007). The reserve experiences equatorial climatic conditions with a temperature of 22.7°C and relative humidity of 59-96%, having an average of 83% (Pius, 2000). The soil is classified as those of Serdang-Kedah series with a combination of local alluvium-colluvium



Figure 1: Geographical Location of Ayer Hitam Forest Reserve

resulting from metamorphic rocks (Pius, 2000).

The Ayer Hitam forest was logged between the period of 1936 to 1951 and several rehabilitation activities have been undertaken to improve the forest ecosystem based on the Malaysian uniform system (MUS), with the post-F inventory carried out in 1995 to ascertain the resources of the reserved forest (Paiman *et al.*, 2007).

2.2 Sampling Procedure and Data Collection

Three experimental plots of 50m x 50m were established and located 1500m apart. The different canopy densities of the 30-year *Depterocarp* forest have a scattered mixture of palm, bamboo and rattan (Amat *et al.*, 2001). The determination of plot sites was based on leaf area index (LAI).

Over the established experimental plots, soil CO₂ efflux, soil temperature, soil moisture, litter fall and soil sampling were randomly collected at 27 sampling points for each of the three forest canopy densities. A detailed study of soil CO₂ efflux and its

environmental and predictor factors was conducted in three different forest canopy densities with the same physical, geographical and environmental conditions during the monsoon period. Soil CO₂ efflux was measured from 0800 hours – 1700 hours each day from 1 November to 31 December, using two constructed continuous open flow chambers of 64cm in height and 50cm width, having a volume of 3250cm³ and surface area of enclosed soil of 2500cm². The ambient air was directed into the chamber from a constructed ambient air stabilizer via tubing, and the chamber was made up of a flow fan for the mixture of CO₂ with a 3cm thick closed foam gasket was placed between the chamber base and the soil collar to prevent leakage.

The chambers were connected to a multi gas-handler (WA 161 model) which provides a channel to regulate the flow of CO₂ from various chambers to a flow meter connected with a CO₂/H₂O gas analyzer (Li-Cor 6262). A standard calibration of CO₂ and H₂O was carried out using silica gel and soda. Soil collars were randomly inserted 3cm into the

soil for 24 hours before commencement of measurement for soil pressure to stabilize and create an equilibrium stage. The measurement lasted for 9 hours each day and the CO₂ efflux was recorded every 5sec over a period of 5min in each chamber, from which an average was calculated to estimate the CO₂ concentration in each chamber. The total soil CO₂ efflux was estimated based on the derived equation:

$$R_s = \sum \frac{(CO_{2\text{chamber}} - CO_{2\text{ambient}})}{A \times T} \\ = g \text{ CO}_2 \text{ m}^{-2} \text{ s}^{-1} \dots \dots [\text{Equation 1}]$$

Where:

R_s is the soil CO₂ efflux (gCO₂m⁻²s⁻¹), CO_{2chamber} and CO_{2ambient} are the CO₂ concentration of chamber and ambient in the chamber, respectively and A is the surface area of the chamber with T as the time.

Soil samples were taken randomly at sampling points over each experimental plot at a depth of 10-100cm. The soil samples were weighed, air dried and then oven dried at 105°C for 48 hours. The soil moisture contents were determined using ISRIC 1993 model while the bulk density determination was done using standard procedure. Furthermore, total organic carbon (TOC) was determined by the Walkley-Black method using a correction factor of 1.33 (Sollins *et al.*, 1999).

Soil temperature and soil moisture were measured at a depth of 5cm at intervals of 5min concurrently with each soil CO₂ chamber reading using soil temperature and moisture probes (Watchdog data logger model 125 spectrum technology and Delmorst model KS-D1) respectively.

To determine the input of litter fall to soil carbon, litter was collected at intervals of 14 days for a period of four months (1 November to 28 February). A 1m x 1m litter trap of 1mm² mesh net was placed 1m above the forest floor to avoid decomposition of the

litter with three litter traps placed on each experimental plot. The samples were weighed and air dried in the laboratory and oven dried at 70°C for at least 48 hours, before weighing and separating into leaves, twigs, fruits and miscellaneous components. Carbon and Nitrogen were determined using a TruMac CNS Macro Analyser (LecoCorp).

The Leaf area index (LAI) was determined using a sunfleck ceptometer (Bolstand and Gower, 1990) to measure the canopy leaf distribution (dense, open and moderate canopy densities). Readings were taken in each of the four cardinal directions with the ceptometer placed horizontally 1m above ground level at each forest stand density (Bolstand and Gower, 1990). The estimated soil CO₂ measurements and environmental factors were determined using a constructed continuous open flow chambers technique connected to a multi-gas handler and a CO₂ analyzer.

Both descriptive and inferential statistics were used to summarize and analyze the data obtained. The one-way analysis of variance (ANOVA) was used to present the means \pm , standard deviation and significant differences of soil CO₂ efflux across the three different forest canopy densities of the forest ecosystem. Similarly, a multi linear regression model was employed to ascertain the impact of the environmental variables on soil CO₂ efflux while correlation analysis was used to show the relationship between the bivariates when the third variable was held constant.

3. RESULTS AND DISCUSSION

Table 1 summarizes the mean values, the standard deviation and standard error of CO₂ efflux over the different canopies while the results of soil properties determined are

Table 1: Mean values of soil CO₂ efflux over the different canopies

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Mini	Max
					Lower Bound	Upper Bound		
Dense Canopies	205	545.0571	179.88619	12.56380	520.2856	569.8287	256.03	1038.82
Open Canopies	216	580.1999	182.92522	12.44648	555.6672	604.7327	118.83	1129.40
Moderate Canopies	220	687.4848	351.03995	23.66711	640.8404	734.1293	275.38	1840.50
Total	641	605.7824	259.65281	10.25567	585.6436	625.9213	118.83	1840.50

Source: Authors' analysis

presented in Table 2. The results from Table 1 show that in the dense canopy forest, values ranged from 256.03-1038.82 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$. Low emission was recorded between 0800hrs and 1100hrs while there was a pronounced increment between 1300hrs and 1500hrs. The mean soil CO₂ efflux recorded was 545.057 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$. Soil temperature and moisture maintained a high rate throughout the period of measurement at 25-27°C and 97-98 mill bytes, respectively.

effluxes across the three forest canopy densities with a significant level of 0.001.

The dense forest canopy soil CO₂ emission range of 256.03-1038.82 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ is related to 255-1529 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ of Japanese cedar in Japan (Choi, 2002) while the lowest emission recorded in the open canopy with a range of 118.83-1129.40 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ is similar to 50-2329 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ of tropical peat land eastern Sumatra Indonesia reported by Mohammed

Table 2: Results of soil physic-chemical properties over different canopies

SAMPLE PLOTS	SOC %	TOC %	pH	Soil moisture content %	Moisture correction factor	Litter falls Carbon %	Litter falls Nitrogen %
Moderate Canopy	4.925	4.6	5.67	37.39	1.37	47.92	1.29
Dense Canopy	4.224	1.4	5.77	1.58	1.02	49.05	1.31
Open Canopy	1.408	2.3	5.67	22.26	1.22	48.10	1.19

Source: Authors' analysis

The open canopy displayed a range of soil CO₂ efflux from 118.83-1129.40 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ and a mean of 580.199 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$. The peak of emission was observed at 11.50am to 2.30pm, while soil temperature and moisture increased with time by 25.20°C to 26.80°C and 97.40 to 97.80% respectively. The moderate canopy flux increased from 275.38-1840.50 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ with a mean of 605.7824 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ while the soil temperature and moisture increased from 24.80°C to 26.50°C and 97.70 to 97.80%, respectively. The ANOVA statistical analysis shows significant differences in soil CO₂

et al., (2006). The highest amount of soil CO₂ efflux was found in the moderate canopy with a reading of 275.38-1184.50 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$, which is similar to the forest ecosystem of China ranging from -341-1193 $\mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ (Xiang *et al.*, 2010).

The results of physiochemical analysis in Table 2 show that soil pH in the three forest ecosystems are slightly acidic, with pH 5.77, pH 5.6, pH 5.67 for the dense canopy, open canopy and moderate canopy respectively.

The SOC in the top soil of 10cm was found to be higher in the moderate canopy, followed by the dense and open canopy with

4.92%, 4.22% and 1.41%, respectively. Similarly, the TOC varies across the three forest ecosystems with 1.4%, 2.3% and 4.6% dense, open and moderate canopy, respectively. The results show a higher moisture content for the moderate canopy (37.39%) and very low moisture content in the dense canopy (1.58%).

The percentage contributions of C and N within the three different canopy stand densities were high, with carbon found to be highest at 49.05% in the dense canopy stand. In addition, the nitrogen was highest at the dense canopy (1.3%) and least (1.19%) in the open canopy stand. Soil CO₂ efflux in relation to several biophysical and environmental

lowest in soil CO₂ efflux but second and third in C and N input from litter fall. This result shows that the litter fall in the three canopy densities is a major predictor in explaining the variation in soil respiration of the different canopy stand densities, as explained by Davidson *et al.*, (2002) and Hibbard *et al.* (2005).

The soil bulk density for dense canopy presented in Figure 2 shows an increase with depth. However, the value dipped slightly at 80cm but increased at a depth of 100cm while bulk density values fluctuated along the various depths across the open and moderate canopies.

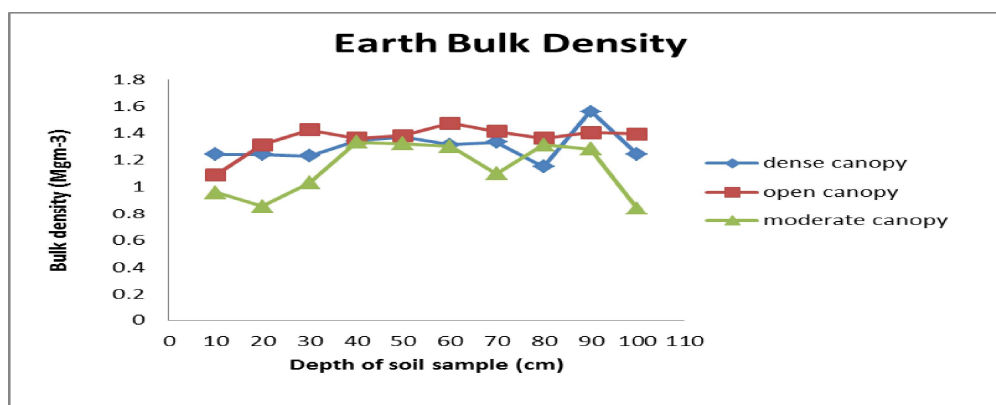


Figure 2: Bulk density values over the different canopies.

Source: Authors' analysis

conditions in terms of litter fall C and N concentration was reported previously by Saiz *et al.* (2006).

The high percentages of C and N in litter fall are attributed to the canopy stand densities in relation to the soil CO₂ efflux in each experimental plot and agree with Curiel *et al.*, (2005). The total Soil CO₂ efflux rate in the moderate canopy density was found to be the highest in the study area but percentage C and N in litter fall place it third and second, respectively. Similarly, the dense canopy density is second in soil CO₂ efflux but highest in C and N input from litter fall. The open canopy density was found to be the

The bulk density in the forest ecosystem was observed to increase with depth, indicating the important role played by pore spaces for microbial activity (Elliot *et al.*, 1980; Doran *et al.*, 1990).

The spatial and temporal variation of the soil CO₂ effluxes showed high impact of soil moisture at 132.927 and temperature at 32.641 in the dense canopy while in the open canopy it displaced an impact of 109.477 and -670.383 of soil temperature and moisture, respectively. The moderate canopy showed a beta coefficient of 714.097 and 26.742 for soil moisture and temperature respectively. The result of multiple linear regression

analysis to test the relationship between soil CO₂ efflux, soil moisture and temperature indicates that an increase in the soil moisture and temperature will cause an increase in soil CO₂ efflux. The model showed that none of the conditional index models for the three different forest canopy densities was above the threshold limit of 30.0. In addition, none of the tolerance values was less than 0.10 indicating no multiple co-linearity problems among the variables of the models. With this condition met, it can be concluded that the estimated multiple linear regression model can be used to explain the impact of soil temperature and moisture on soil CO₂ efflux.

Generally, the results indicate that soil CO₂ efflux rates are in response to the increase in soil organic carbon (SOC), total organic carbon (TOC), carbon (C), nitrogen (N), soil moisture content and slight acidity, as reported by Joshi (1994) and Ming Xu (2001). This suggests that the soil CO₂ rate is based on the protein provided in the microbial activity and roots (Tewery *et al.*, 1982). The highest soil CO₂ efflux in the moderate canopy can be attributed to the high percentages of SOC, TOC, C, N and soil moisture content. The soil CO₂ efflux rate estimated at the three ecosystems based on the canopy densities are within the range emitted by a 39-year larch stand in Korea (Choonsig, 2006) but greater than the soil forest of Hokkaido Japan (Ronggui *et al.*, 2001) and paddy ecosystem in China (Ren *et al.*, 2007). The highest amount of soil CO₂ efflux observed in the moderate canopy is related to the high amount of soil moisture content and the role of microbial activity due to the presence of SOC, TOC and litter fall in the moderately acidic soil and soil pore spaces. The open canopy with less canopy density and litter input gave rise to the low amount of SOC and TOC, thereby emitting low soil CO₂ efflux. Soil moisture was found to have a high impact on both the dense and open canopies compared to the soil

temperature. However, the soil temperature has greater impact than the soil moisture in the open canopy, which accounts for the most spatial and temporal variation in soil CO₂, therefore suggesting that environmental variables are the controlling factors in soil CO₂ efflux.

4. CONCLUSION AND RECOMMENDATIONS

The study assessed soil CO₂ efflux under different forest canopy densities of Ayer Hitam Forest in Malaysia. The total amount of Soil CO₂ efflux from each forest canopy density showed that the moderate canopy forest ecosystem displayed the highest rate of CO₂ efflux at 39.772gCO₂m⁻²s⁻¹. This showed that the interaction between the soil CO₂ efflux and soil temperature, moisture, total organic carbon (TOC), soil organic carbon (SOC), litter fall, soil PH and bulk density had a strong influence and impact on the soil CO₂ emission rate. Similarly, the beta coefficient relationship suggests that the environmental factors have considerable influence on soil CO₂ efflux.

It is concluded that environmental variability and biological processes dominate soil CO₂ efflux and should be taken into cognisance in determining and improving the estimation of soil CO₂ efflux in any ecosystem. It is important to note that the results were obtained in the tropical rainforest during the monsoon period of the peninsula. This may have an influence on the environment and biological processes and differ from other seasons and ecosystems. Nevertheless, the results will help to improve the estimation of soil CO₂ efflux for various ecosystems under different stand densities, as influenced by the environmental and predictor factors in the tropical forests of Malaysia.

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