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Drivers of Soil Carbon Dioxide Efflux in a 70 years Mixed Trees Species of Tropical Lowland Forest, Peninsular Malaysia

(Pemacu kepada Karbon Dioksida Efluks Tanah dalam Masa 70 Tahun Campuran Spesies Pokok di Hutan Tropika Tanah Rendah, Semenanjung Malaysia)

K.H. MANDE, A.M. ABDULLAH*, A.A. ZAHARIN, & A.N. AINUDDIN

ABSTRACT

Forest biomass is a major component in carbon sequestration and a driver of heterotrophy and autotrophy soil CO_2 *efflux, as it accumulation increases carbon organic nutrients, root growth and microbial activity. Understanding forest biomass rational to ascertain the forest ecosystems productivity is important. A study has been conducted in a 70-year-old forest of mixed tree species, Sungai Menyala Forest, Port Dickson, Peninsular Malaysia, measuring the total above ground biomass (TAGB), below ground biomass (BGB), total forest carbon (SOCs), soil organic carbon stock (SOCstoc) and soil* CO_2 *efflux from 1 February to 30 June 2013. The aim was to determine the effect of forest biomass, litter fall and influence of environmental factors on soil* CO_2 *efflux. Multiple regression analysis has been conducted on the relationship between the variables and the soil* CO_2 *efflux. Soil* CO_2 *efflux was found to range from 92.09-619.67 mg* m^{-2} h^{-1}*, with the amount of the tropical forest biomass estimated at* 1.9×10^6, 7.7×10^6 *and* 9.2×10^5 *kg for TAGB, BGB and SOCs, respectively. The analysis showed a strong correlation between soil* CO_2 *efflux and soil temperature, soil moisture, water potential and forest carbon input with* R^2 *more than 0.89 at* $p<0.01$*. The findings showed a strong contribution from forest biomass as drivers of heterotrophy and autotrophy soil* CO_2 *efflux. We can conclude that the forest biomass and environmental factors are responsible for the remarkable variation in soil* CO_2 *efflux, as climate change can cause increase in temperature as well as deforestation decreases forest biomass.*

Keywords: Autotrophy; carbon input; forest biomass; heterotrophy; microbial activities; soil CO_2 *efflux*

ABSTRAK

Biojisim hutan adalah komponen utama dalam perampasan karbon dan pemacu kepada CO_2 *efluks tanah secara heterotrofi dan autotrofi dengan meningkatnya penghimpunan nutrien karbon organik, pertumbuhan akar dan aktiviti mikrobiologi. Pemahaman biojisim hutan yang rasional kepada penentuan produktiviti ekosistem hutan adalah penting. Satu kajian telah dijalankan di dalam hutan yang berusia 70 tahun dengan kepelbagaian spesies pokok, di Hutan Sungai Menyala, Port Dickson, Semenanjung Malaysia, dengan pengukuran jumlah biojisim di atas tanah (TAGB), biojisim di bawah tanah (BGB), jumlah karbon hutan (SOCs), stok karbon organik tanah (SOCstoc) dan juga* CO_2 *efluks tanah dari 1 Februari hingga 30 Jun 2013. Kajian ini bertujuan untuk menentukan kesan biojisim hutan, gugurnya kekotoran serta pengaruh faktor alam sekitar terhadap* CO_2 *efluks tanah. Analisis pengunduran gandaan telah dijalankan dalam penentuan hubungan antara pemboleh ubah dengan* CO_2 *efluks tanah.* CO_2 *efluks tanah didapati berada dalam julat 92.09-619.67 mg* m^{-2} h^{-1}*, dengan jumlah biojisim hutan tropika dianggarkan pada* 1.9×10^6 *kg,* 7.7×10^6 *kg,* 9.2×10^5 *kg masing-masing bagi TAGB, BGB dan SOCs. Analisis menunjukkan perhubungan yang kuat antara* CO_2 *efluks terhadap suhu tanah, kelembapan tanah, keupayaan air dan input karbon hutan dengan nilai* R^2 *melebihi 0.89 pada nilai* $p<0.01$*. Penemuan ini menunjukkan sumbangan yang kuat daripada biojisim hutan sebagai pemacu heterotrofi dan autotrofi* CO_2 *efluks tanah. Disimpulkan bahawa biojisim hutan dan faktor-faktor alam sekitar bertanggungjawab terhadap kepelbagaian yang menakjubkan dalam* CO_2 *efluks tanah, dengan perubahan iklim boleh menyebabkan pertambahan suhu begitu juga menurunnya biojisim hutan melalui penyahhutanan.*

Kata kunci: Aktiviti mikrobial; autotrofi; biojisim hutan; CO_2 *efluks tanah; input karbon; heterotrofi*

INTRODUCTION

Soil CO_2 efflux is one of the paths to atmospheric carbon and it dynamic process is being influence by climatic factors, human activities and natural process. On the other hand, fossil fuel burning has been identified as a contributing factor in global carbon cycling but the forest which serve as a carbon sink and source could release vast amount of carbon dioxide when disturb. Studies showed various percentage of soil CO_2 into the atmosphere contributed from different ecosystems of the tropical lowland forests, temperate forests and tropical grasslands. Raich and Schlesinger (1992) found CO_2 to be emitted at

1092, 662 and 629 g C m^{-2} yr^{-1} in the tropical lowland, temperate forest and tropical grasslands, respectively, indicating higher emission rate, while moderate emission rates was recorded to be at 544, 442 and 322 g C m^{-2} yr^{-1} in the cultivated lands, temperate grasslands, and boreal forests, respectively. Desert scrub vegetation, swamps and marshes and tundra have the lowest CO_2 efflux rates at 224, 200 and 60 g C m^{-2} yr^{-1}, respectively. The magnitude of the total amount of soil CO_2 efflux into the atmospheric carbon pool is estimated to be 68–100 Pg C/year (Akburak & Makineci 2013), which could have a negative impact on the atmosphere and hence contribute to climate change (Tang et al. 2006).

To investigate the major source of carbon dioxide, much attention has been paid to soil CO_2 efflux in the present century as soil is acknowledged to contain twice as much carbon as the atmosphere (Coleman et al. 2002), is responsible for carbon efflux and is a key component of the carbon cycle in terrestrial ecosystems. Raich et al. (2002) reported that soil CO_2 efflux is ten times greater than that from deforestation and fossil fuel combustion on a global scale, with about 40–90% of ecosystem respiration generated by soil CO_2 efflux in the forest ecosystem (Akburak & Makineci 2013).

Attention has been focused on the tropical forest ecosystem as conversion and deforestation of the forest to permanent croplands account for approximately 75% of the total CO_2 emission from tropical Asia (Houghton & Hackler 1999). The tropical forest ecosystem stand to play a major role in the global terrestrial carbon cycle as its vegetation and soil contain approximately 37% of the global terrestrial carbon pool and any change in the tropical CO_2 fluxes would change the global carbon budget (Dixon et al. 1994). However, there is still limited knowledge concerning the environmental factors and forest biomass from the various tree species controlling soil CO_2 flux in the tropical forestry ecosystem; in addition, it is important to understand the rationale behind the heterotrophy and autotrophy soil CO_2 efflux drivers, environmental factors and forest biomass from different tree species responsible for soil CO_2 efflux.

Soil CO_2 efflux varies significantly among different biomes and the rate of CO_2 efflux is affected by vegetation type. The various vegetation of tree species and the quantity and quality of litter fall, stand density and structure have an impact on the soil CO_2 efflux by changing the soil microclimate (Akburak & Makineci 2013). This scenario indicates that various tree species are significant indicators of the soil respiration rate and any disturbance in these vegetation patterns will greatly affect the response of the soil to environmental change (Raich & Tufekcioglu 2000). The objectives of this study were to ascertain the impact of forest biomass, litter fall and the role of various tree species on the total aboveground biomass and below carbon stock and to evaluate the significance relationship of the combined function of environmental factors on the rate of soil CO_2 efflux.

MATERIALS AND METHODS

SITE DESCRIPTION

The study was carried out in a 70-year-old forest of mixed trees species of *Dipterocarpus baudii, Dipterocarpus verruscosus, Shorea pauciflora, Shorea bracteolata, Shorea* spp, *Shorea acuminata, Shorea parvifolia, Shorea macroptera, Shorea leprosula* and *Kopmpassia malaccensis,* located at Sungai Menyala forest (27^{0}51′93″N, 45^{0}35′69″E) of Negeri Sembilan, Peninsular Malaysia. The forest experiences an equatorial climatic condition with a mean temperature range of 23.7-32ºC and relative humidity of 59-96%. The wet and humid tropical climate experiences a monsoon period that occurs between November and January with a monthly rainfall of 200 mm and the post-monsoon, which also experiences the occurrence of light showers between February and September. The soil is dominated by a red colour derived from the alluvium colluvium resulting from metamorphic rock.

EXPERIMENTAL DESIGN, MEASUREMENT OF SOIL CO_2 EFFLUX AND RELATED ENVIRONMENTAL PARAMETERS

Total of six plots were established; consisting of two plots of 50×50, 70×70 and 100×100 m each to study the total above ground biomass (TAGB) variation. The smallest plot size (50×50 m) was selected because the number of trees and species diversity increase insignificantly as the plot sizes increases due to the fact that the mixed forest is dominated by ten species. Thirty sampling points were established and soil collars were inserted 3 cm into the soil for 24 h to create an equilibrium stage before chambers were placed on them, with a 3 cm thick closed foam gasket to prevent leakage from the chamber base.

Two continuous open flow chambers, 64 cm in height and 50 cm width, with a volume of 3250 cm^3 and enclosed soil surface area of 2500 cm^2, connected to a multi gas-handler (WA 161 model), which provides a channel to regulate the flow of CO_2 from various chambers to a flow meter connected to a CO_2/H_2O gas analyser (Li-Cor 6262) and finally, to a computer system, which were used for the measurement of soil CO_2 efflux. Soil temperature, soil moisture and water potential were measured at 5 m depth using soil temperature probes, moisture probes and Trime-FM TDR (Watchdog data logger model 125 spectrum technology, Delmorst model KS-D1 and Trime-Fm TDR, respectively) simultaneously with soil CO_2 efflux at a point close to the soil collar. The measurements lasted for 9 h (0800 to 1700 h) each day from 1 February 2013 to 30 June 2013. Soil CO_2 efflux was recorded every 5 s over a period of 5 min in each chamber, from which an average was calculated to estimate the CO_2 concentration over 5 min for each chamber.

SOIL SAMPLING AND ANALYSIS

Soil samples were collected from a depth of 0 to 100 cm from three sampling points for analysis of total organic carbon (TOC), soil organic carbon (SOC), earth bulk density, soil pH, electric conductivity (EC) and cation exchange capacity (CEC), using the soil core with a metal core sampler of 10 cm in diameter and 10 cm in height. The volume of the core sampler was determined using the following:

$$V = \pi r^2 h, \tag{1}$$

where V is the volume (cm^3); r is the radius of the core sampler (cm) and h is the height of the core sampler (cm). The soil samples were weight, air dry and oven dry at 105°C for 48 h.

Earth bulk density, which indirectly provides a measure of the soil porosity (pore spaces) was determined using the standard method of soil analysis.

$$Earth\ bulk\ density\ (Mgm^{-3}) = {}^{g}/_{V}, \tag{2}$$

where g is the oven dry mass of the sieve soil (g) and V is the sample volume (mL).

The soil moisture content was determined in accordance with the standard method based on the following:

Moisture content in wt% ($^{W}/_{W}$) is obtained by:

$$Moist\ (wt\%) = \left[\frac{(A-B)}{(B - tare\ tin)}\right] \times 100. \tag{3}$$

The corresponding moisture correction factor (mcf) for analytical results as:

$$Moisture\ correction\ factor = (100 + \%moist)/100,$$

where A is the air dry soil and B is the oven dry soil.

The total organic carbon (TOC) was determined by the Walkley-black method using a correction factor of 1.33 (Sollins et al. 1999), as it is appropriate for moisture analyses because of its simplicity:

$$TOC\ (\%M) = M \times \left[{}^{(V1-V2}\!/_{S}\right] \times 0.39\ x\ mcf, \tag{4}$$

where M is the molarities of ferrous sulphate solution (from blank titration); V1 mL is the ferrous sulphate solution required for blank; V2 mL is the ferrous sulphate solution required for S is the weight of air dry sample in grams and mcf is 3 (equivalent weight of carbon) corrected factor.

Soil organic carbon (SOC) was determined using the following:

$$M = {}^{10}/_{Vblank}. \tag{5}$$

$$\%\ oxidizable\ organic\ carbon\ ({}^{W}/_{W}) = (Vblank - Vsample)\ /_{\ wt}\ x\ 0.3\ x\ mass. \tag{6}$$

$$\%total\ organic\ carbon\ ({}^{W}/_{W}) = 1.334\ x\ \%\ oxidazable\ organic\ carbon. \tag{7}$$

$$\%organic\ matter\ ({}^{W}/_{W}) = 1.724\ x\ \%total\ organic\ carbon, \tag{8}$$

where M is the molarities of ferrous ammonium sulphate solution (app 0.5 mL) and V blank is the volume of ferrous ammonium sulphate solution required to titrate the blank (mL) = Volume of ferrous ammonium sulphate solution required to titrate the sample (mL); wt is the weight of air dry soil (g) and 0.3 = 3 × 10^{-3} × 100 where 3 is the equivalent weight of C.

The soil organic carbon stock was ascertained to verify the amount of the stock of carbon held in a given area of the soil, taking cognisance of the compaction and depth of the soil while the earth bulk density had to be determined. The soil depth recommended for the stock of carbon assessment is the top 100 cm (Eleanor 2008). The soil organic carbon stock held in a given area of soil can be then expressed as:

$$SOCstock = \left[\frac{SOC\ content\ of\ soil \times BD \times area \times depth}{10}\right], \tag{9}$$

where SOC is the soil organic carbon; BD is the bulk density and depth is the depth of the soil.
Soil pH and electric conductivity was determined.

LEAF AREA INDEX (LAI), LITTER FALL, TOTAL ABOVEGROUND BIOMASS, TOTAL BELOW GROUND BIOMASS, SOIL ORGANIC CARBON STOCK AND TOTAL FOREST CARBON STOCK

The site characteristics of the 70-year-old forest mixed trees species were confined to the central area of the plot to reduce the edge effects and also the plot area was found to have an average high homogeneity of abiotic environmental conditions (slope, elevation and soil type). The parameters determined include: Canopy stand density (LAI) to ascertain light intensity and stand density, using an Asunfleckceptometer (AccuPAR model sf-80, Decagon, Pullman, WA). The litter fall collection for carbon and nitrogen ratio (C:N) determination was conducted using the TruMac CNS Macro Analyser (LecoCorp). To avoid decomposition, the leaf samples were collected at intervals of two weeks for a period of five months from ten litter traps of 1×1 m and 1 mm^2 mesh nets placed 1 m above the forest floor. The leaves were weighed and air dried in the laboratory and oven dried at 70°C for at least 48 h, then weighed and separated into leaves, twigs, fruits and miscellaneous components and later blended. A total number of 111 trees established within the plot were measured for tree height and diameter breast height (DBH) using DBH tape, 1.3 m above the forest floor of each tree (Manokaran et al. 1990). The data were generated to calculate the total above ground biomass (TAGB), below ground biomass (BGB), total forest carbon (SOCs) and soil organic carbon stock (SOCstock) based on the model of Kato et al. (1978). This was conducted to establish a linear relationship with soil CO_2 efflux in the post monsoon period. The model estimates the tree stem, branch and leaf biomass. The affirmative components form the total above ground biomass (TAGB) based on the simple regression lines fitted for DBH and tree height:

$$\text{Tree height (H)}\ \frac{1}{H}=\frac{1}{\left(a.D\right)}+\frac{1}{MaxHt}, \qquad (10)$$

where H is the tree height (m); D is DBH (cm); $MaxHt$ is the maximum tree height (m) and a is a coefficient where 2.0 for trees with DBH>4.5cm.

Weight (kg) of main stem (Ws):

$$Ws = 0.313\ (D^2\ H)^{0.9733}. \qquad (11)$$

Weight (kg) of branches (Wb):

$$Wb = 0.313\ (D^2\ H)^{1.041}. \qquad (12)$$

Weight (kg) of leaves (Wl):

$$\frac{1}{Wl}=\frac{1}{\left(0.124.Ws^{0.794}\right)}+\frac{1}{125}. \qquad (13)$$

Total above ground biomass (TAGB) was calculated as:

$$TAGB = Ws + Wb + Wl. \qquad (14)$$

The below ground carbon biomass was estimated using the model of Ogawa et al. (1963):

$$Root\ (W_R) = 0.0264\ (D^2\ H)^{0.775}. \qquad (15)$$

The total forest carbon stock was estimated based on the carbon content of the biomass. The default value for the carbon content on biomass is 0.47, which varies according to country, was calculated as:

$$C_b = B\ x\ \%\ C\ organic, \qquad (16)$$

where C_b is the carbon content from biomass; B is the total biomass and $\%C\ organic$ is the percentage value for carbon content, amounting to 0.47 default value or laboratory obtained value.

STATISTICAL ANALYSIS

Data for soil CO_2 efflux and environmental factors were subjected to various analysis using statistical packages. Analysis of variance (ANOVA), version 21.0 of the SPSS software (SPSS Inc., Chicago, Illinois, USA) was employed to present the means ± based on the least significant difference (LSD) method, standard deviation of (n) and significance of the various tree species soil CO_2 efflux, all with a significance level of $p<0.05$. The descriptive statistics employed was used to explain the normality of data distribution and the relationship of soil CO_2 and environmental parameters, respectively. Partial correlation shows the relationship between the bivariate when the third variable is held constant and the multiple linear regression model was implemented to ascertain the impact of the environmental variable to soil CO_2 efflux. The technique can be used for both predictive and explanatory purposes with the experimental and non-experimental design, which can be represented as:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots\ \ldots + \beta_p X_{ip} + \varepsilon_i, \qquad (17)$$

where Y_i is the i^{th} observation of the dependent variable, X_{ij} is i^{th} observation of the j^{th} independent variable and $j = 1, 2, ..., p$. The value β_j represents the parameters to be estimated and ε_i is the i^{th} independent identically distributed normal error.

RESULTS

SPATIAL AND TEMPORAL DYNAMIC OF SOIL CO_2 EFFLUX

The diurnal pattern of soil CO_2 efflux from the five months measurement from 1 February 2013 to 30 June 2013 displaced an average of 92.09 to 619.67 mg m^{-2} h^{-1}, rising in the morning and attaining the highest peak in the afternoon before declining as the sun sets. Soil CO_2 efflux showed a moderate range across the five months, with a daily rate of 122.19-619.67, 105.07-444.43, 100.24-426.19, 92.09-450.76 and 103.43-536.05 mg m^{-2} h^{-1} for the months of February, March, April, May and June 2013, respectively (Table 1). The maximum value occurred in February, which coincided with the end of the monsoon period with a higher soil moisture, moderate water potential and soil temperature of 26.00-28.82%, 93.5-97.5% and 24.57-26.24°C, respectively. A decrease in the efflux rate was observed in March and April, with a pronounced increment from May to June and having a positive correlation ($p<0.001$) with soil moisture, water potential and soil temperature at an average of 21.6-25.91%, 97.01-98.3% and 23.35-25.69°C, respectively.

THE IMPACT OF SOIL TEMPERATURE, MOISTURE AND WATER POTENTIAL ON SOIL CO_2 EFFLUX

The general significant positive impact of soil temperature, moisture and water potential was explained using the multiple regression model. The beta coefficient for soil temperature, moisture and water potential in the month of February were -.281, -.901 and -.049, respectively, which indicated that soil CO_2 efflux occurred while the three environmental factors were held constant (Table 2). Soil temperature occurred with an increase in soil CO_2 efflux while soil moisture and water potential were held constant at .151, -.501, -.584 beta coefficient in March (Table 3). The April measurement showed that soil temperature and moisture highly influence soil CO_2 efflux while the water potential was constant at a beta coefficient of .229, .231, -.635, respectively (Table 4). The exponential impact was observed for the soil temperature, moisture and water potential on soil CO_2 efflux at .140, .180, .578 beta coefficient, respectively (Table 5). For the month of June, the environmental factors, soil temperature and moisture, were constant while the water potential increased with the increase in soil CO_2 efflux at -.035, -.262, .739, respectively (Table 6). The general trends of the soil temperature, soil moisture and water potential emission rate were parallel to the soil CO_2 efflux with a gradual increase in the morning, attaining a peak in the afternoon and decreasing as the sun set (Figures 1 and 2).

The regression model employed gave the best fit of dependence of soil CO_2 efflux on soil temperature, moisture and water potential for the five months at a high R-square (Table 7). The correlation statistics indicated a high to very high significant relationship.

IMPACT OF TOTAL ABOVE GROUND BIOMASS, TOTAL BELOW GROUND BIOMASS, TOTAL FOREST CARBON STOCK, SOIL ORGANIC CARBON STOCK AND LITTER FALL ON SOIL CO2 EFFLUX

Five drivers of soil CO_2 efflux were identified: Total above ground biomass (TAGB), below ground biomass (BGB), forest carbon stock (SOCs), soil organic carbon stock (SOC stock) and litter fall. Their high percentage occurrence has a significant effect on soil CO_2 efflux through the carbon input for microbial activities (Saiz et al. 2006). The ten mixed trees species in the 70-year-old forest host an estimated forest biomass of 1878095, 77098.75 and

TABLE 1. Descriptive statistics of soil CO_2 efflux (mg m^{-2} h^{-1})

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
February soil CO2 efflux	72	394.8711	143.68060	16.93292	361.1078	428.6344	122.19	619.67
March soil CO2 efflux	72	235.1175	99.28255	11.70056	211.7873	258.4478	105.07	444.43
April soil CO2 efflux	72	225.7500	90.25903	10.63713	204.5402	246.9598	100.24	426.19
May soil CO2 efflux	72	238.5457	106.22411	12.51863	213.5843	263.5072	92.09	450.76
June soil CO2 efflux	72	324.3424	124.55017	14.67838	295.0745	353.6102	103.43	536.05
Total	360	283.7254	131.56274	6.93397	270.0891	297.3616	92.09	619.67

TABLE 2. Seventy years forest estimates of coefficient of the model of environmental parameters in °C and % for soil temperature and soil moisture in February

Model		Unstandardized coefficients		Standardized coefficients Beta	t	Sig.	Collinearity statistics	
		B	Std. Error				Tolerance	VIF
1	(Constant)	24462.442	6216.055		3.935	.000		
	FEBst	-103.009	23.061	-.281	-4.467	.000	.768	1.302
	FEBmt	-666.326	142.233	-.901	-4.685	.000	.082	12.121
	FEBwp	-25.166	102.569	-.049	-.245	.807	.076	13.093

a.Dependent Variable: FEBCO2. FEBst= February soil temperature, FEBmt=February soil moisture, FEMwp=February water potential

TABLE 3. Seventy years forest estimates of coefficient of the model of environmental parameters in °C and % for soil temperature and soil moisture in March

Model		Unstandardized coefficients		Standardized coefficients Beta	t	Sig.	Collinearity statistics	
		B	Std. Error				Tolerance	VIF
1	(Constant)	34390.622	2080.747		16.528	.000	.518	1.929
	MARst	36.659	18.067	.151	2.029	.046	.563	1.776
	MARmt	-622.361	88.611	-.501	-7.024	.000	.476	2.101
	MARwp	-207.671	27.558	-.584	-7.536	.000		

a. Dependent Variable: MARCO2. MARst=March soil temperature, MARmt=March soil moisture, MARwp=March water potential

TABLE 4. Seventy years forest estimates of coefficient of the model of environmental parameters in °C and % for soil temperature and soil moisture in April

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.	Collinearity statistics	
		B	Std. Error	Beta			Tolerance	VIF
	(Constant)	180721.424	18841.068		9.592	.000		
	APLst	31.861	10.812	.229	2.947	.004	.565	1.770
1	APLmt	24.785	7.628	.231	3.249	.002	.670	1.493
	APLwp	-1867.518	192.279	-.635	-9.713	.000	.796	1.256

a. Dependent Variable: APLCO2; APLst=april soil temperature, APLmt=april soil moisture, APLwp=april water potential

TABLE 5. Seventy years forest estimates of coefficient of the model of environmental parameters in °C and % for soil temperature and soil moisture in May

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.	Collinearity statistics	
		B	Std. Error	Beta			Tolerance	VIF
	(Constant)	-28286.766	8892.636		-3.181	.002		
	MAYst	51.502	45.576	.140	1.130	.262	.662	1.511
1	MAYmt	239.959	189.402	.180	1.267	.210	.502	1.993
	MAYwp	220.782	57.539	.578	3.837	.000	.450	2.224

a. Dependent Variable: MAYCO2. MAYst=May soil temperature, MAYmt=May soil moisture, MAYwp=May water potential

TABLE 6. Seventy years forest estimates of coefficient of the model of environmental parameters in °C and % for soil temperature and soil moisture in June

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.	Collinearity statistics	
		B	Std. Error	Beta			Tolerance	VIF
	(Constant)	-99926.706	12828.656		-7.789	.000		
	JUNst	-27.267	58.952	-.035	-.463	.645	.583	1.717
1	JUNmt	-594.180	180.452	-.262	-3.293	.002	.524	1.907
	JUNwp	1184.942	106.725	.739	11.103	.000	.751	1.331

a. Dependent Variable: JUNCO2. JUNst=June soil temperature, JUNmt=June soil moisture, JUNwp=June water potential

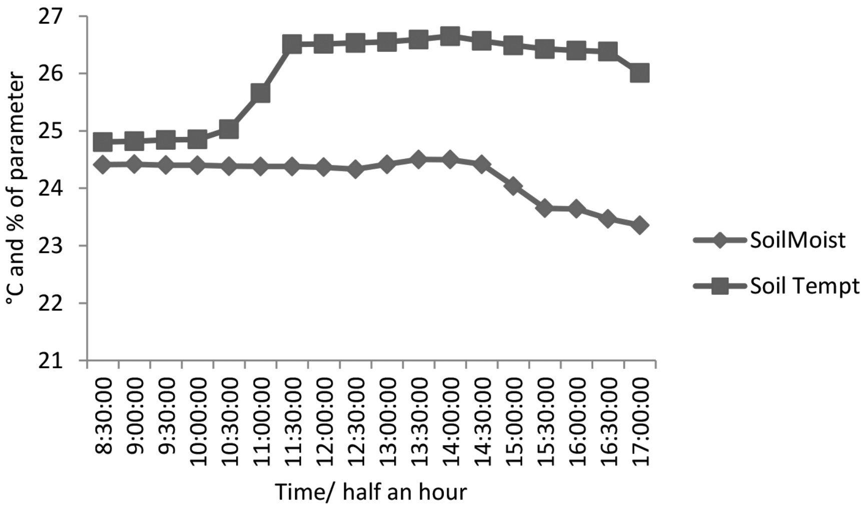

FIGURE 1. Soil temperature and moisture across five months

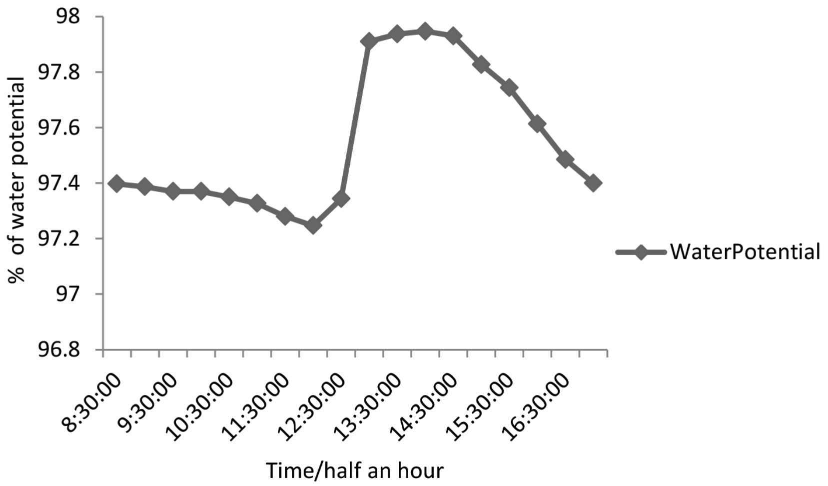

FIGURE 2. Water potential across five month

TABLE 7. Best single and multiple-regression models were generated using enter independent variable selection

Model	R Square	Adj- R^2	Std error of estimation	F	Sig
February	.890	.793	66.85381	86.649	<0.001
March	.897	.805	44.76093	93.769	<0.001
April	.877	.759	44.33856	75.408	<0.001
May	.554	.307	90.32910	10.062	<0.001
June	.880	.774	60.56163	77.433	<0.001

918940.9 kg and 69.44 Mg/ha of TAGB, BGB, SOCs and SOC stock, respectively, with C/N from litter fall of 50.11-51.86 and 1.41-1.58, respectively (Table 8). The enormous abundance of this forest biomass significantly serves as the driver for the overall soil CO_2 efflux in the availability of the soil moisture, water potential and high soil temperature during the post monsoon season of the tropical climate.

IMPACT OF TOC, SOC, SOIL MOISTURE CONTENT, PH AND EARTH BULK DENSITY ON SOIL CO_2 EFFLUX

The red soil of the study area showed its physiochemical properties to contain TOC and SOC of 2.4 and 4.96%, respectively, soil moisture content of 19.0% with moisture correction factor occurring at 1.19% and a slightly acidic soil of pH5.10 (Table 8). The bulk density was observed to increase with the depth from 0 to 100 cm, giving good porosity for electric conductivity, cation exchange and free flow rate of water for the microbial metabolism. (Figure 3). These parameters are attributed to the availability of the forest biomass contribution in the presence of changing soil temperature, moisture and water potential.

Discussion

SOIL CO_2 EFFLUX

The results obtained from the analysis of soil samples indicated a high percentage of TOC, SOC and C/N ratio, which suggested that carbon nutrients contributed by the forest biomass are triggering important changes in the soil and microbial activities, as was also reported by Asensio et al. (2012). The change in soil temperature, soil moisture and water potential due to the gradual change from the monsoon to the post monsoon period of the tropical climate

TABLE 8. Analysis of soil samples, litter fall, forest biomass and carbon

ECOSYSM	SOC %	TOC %	pH	Soil Moisture Content %	Moisture Correction Factor	Litter falls Carbon % Nitrogen %	SOCstock Mg/ha	TAGB Kg	BGB Kg	SOCs Kg
Thirty Years Forest	4.96	2.4 5.10	19.0	1.19	50.11 - 51.86	1.41 - 1.58	69.44	1878095	77098.75	918940.9

a.SOCstock=Soil organic carbon stock, TAGB=Total Above Ground Biomass, BGB=Total Below Ground Biomass, SOCs=Total Forest Carbon Stock

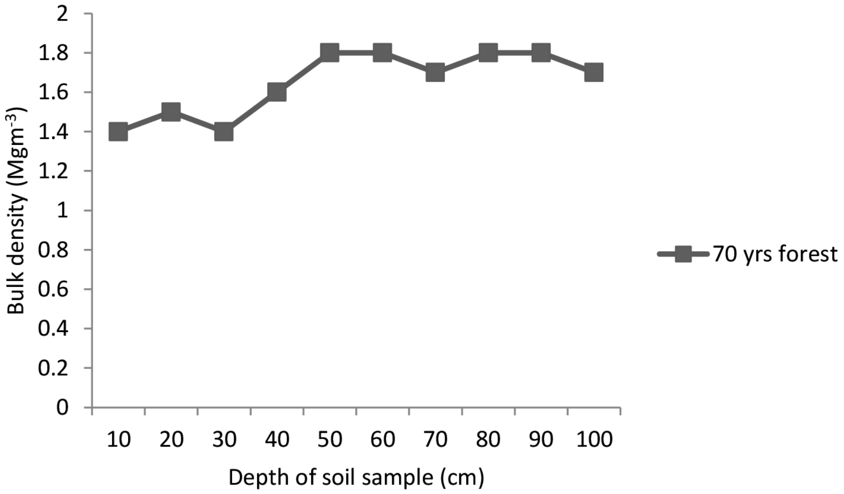

FIGURE 3. Result of bulk density

condition has a significant effect on the environmental condition. In addition, the favourable soil pH and increase in bulk density accelerates the microbial activity. All of which, in turn, contributes to soil CO_2 efflux.

Based on this finding, it was clear that the spatial and temporal high soil CO_2 efflux trend across the forest ecosystems (Figure 4) was attributed to the high percentage of the forest biomass and carbon; TAGB, BGB, SOCs and SOCstock, as potential sources for energy and carbon and the combined influence of the change in the environmental factors resulted from the tropical climate. The average soil CO_2 efflux rate of 92.09-619.67 mg m^{-2} h^{-1} in the 70-year-old forest of ten mixed species was similar to the soil respiration in the canopy field of China (Jin et al. 2009). The highest soil CO_2 efflux rate was recorded in February, the beginning of the post monsoon, with an efflux range of 122.19-619.67 mg m^{-2} h^{-1}. A decrease in the months of March to April was observed at a range of 105.07-444.43 and 100.24-426.19 mg m^{-2} h^{-1}, respectively; a little higher than the soil respiration in the deciduous forest of Japan due to seasonal change (Lee et al. 2003). There was an instantaneous increase in soil CO_2 efflux from the month of May to June, ranging from 92.09-450.76, 102.43-536.05 mg m^{-2} h^{-1}, similar to the Pasoh Forest Reserve of Peninsular Malaysia (Adachi et al. 2006). The higher soil CO_2 efflux was attributed to the greater contribution of forest biomass to below ground carbon in order to maintain nutrients for supporting root growth and microbial activity (Davidson et al. 2002). The ANOVA statistical analysis showed normality of distribution of soil CO_2 efflux data aligned along the straight line without any outliers, giving good skewedness (Figure 5).

EFFECT OF ENVIRONMENTAL FACTORS ON SOIL CO_2 EFFLUX

The spatial and temporal variation of soil CO_2 efflux across the five months was affected by a variation in the soil temperature and moisture of the post monsoon season. Previous research has attributed a strong relationship between the soil CO_2 efflux and the change in soil temperature, moisture and water potential (Shi et al. 2009; Wu et al. 2006). To some extent, the age and species of forest trees have a great influence on the soil temperature, moisture and water potential (McCarthy & Brown 2006). In our findings, the canopy cover, coupled with the post monsoon season had a significant impact on the environmental factors, as it explained the increase in net radiation and decrease in transpiration on the forest floor (Tanaka & Hashimoto 2006). This scenario, in turn, increases the microbial activity resulting in an increase in soil CO_2 efflux.

FOREST BIOMASS AS DRIVERS OF SOIL CO_2 EFFLUX

Differences in forest trees species, age and canopy density are found to influence the rate of soil carbon stock and sequestration (Sartori et al. 2007; Teklay & Chang 2008). This has been observed as a result of the amount and quality of organic matter through litter fall (C/N) and root activity (Jandl et al. 2007). The observed input from the forest biomass of TAGB, BGB and SOCs was high, thereby increasing the soil carbon stock at 0-100 cm by 69.44 Mg/ha, similar to Ravindranath et al. (1997) and giving a C/N ratio of 50.11-51.86%. This result confirmed the significant role played by the forest biomass of various trees species as a driver to influence the variation in soil CO_2 efflux, also as reported by Hibbard et al. (2005).

CONCLUSION

This study approve that the soil organic carbon, soil properties and microclimatic condition influence the heterotrophy and autotrophy soil CO_2 efflux. The environmental factors such as soil temperature, soil moisture and water potential played important functional role as the net radiation increase on the forest floor in the afternoon raised the environmental conditions to

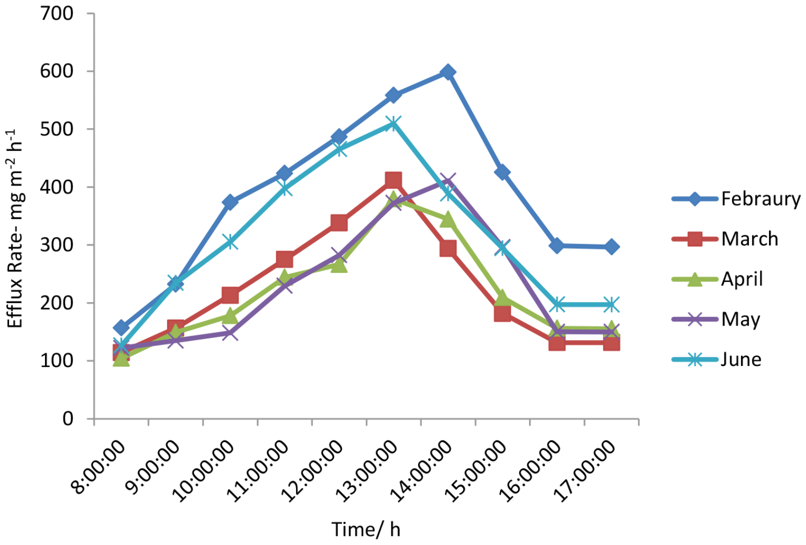

FIGURE 4. Soil CO_2 efflux trend across five months

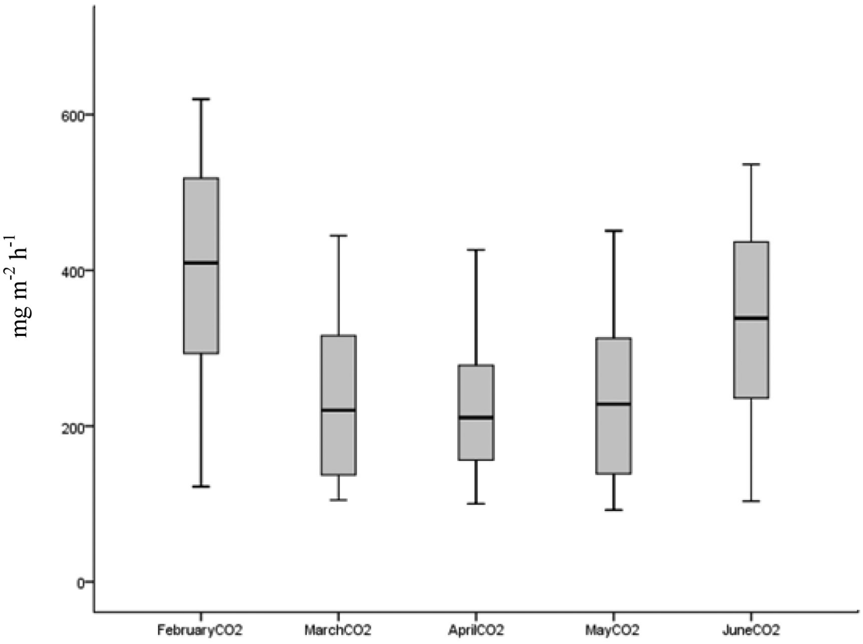

FIGURE 5. Box and whisker plot of soil CO_2 efflux

necessitate soil CO_2 efflux. In addition, forest biomass contributes to soil properties such as TOC and SOC from decomposition process which provides food to micro-organism. Subsequently, decomposition process increase as temperature increases causing increase in soil CO_2 efflux. Furthermore, the combined interactions of these factors determine the dynamic of soil CO_2 efflux. The forest biomass and the microclimatic conditions are important drivers to the carbon balance in which these two components can be affected by human activity. Logging, deforestation activity and climate change could affect these factors changing the role of forest as carbon sink and source. The root production and soil nutritional properties could have influence on the soil CO_2 efflux and should be further explore.

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K.H. Mande
Air Pollution & Ecophysiology Laboratory
Faculty of Environmental Studies
Universiti Putra Malaysia
43400 Serdang, Selangor Darul Ehsan
Malaysia

A.M. Abdullah*
Department of Environmental Sciences
Faculty of Environmental Studies
Universiti Putra Malaysia
43400 Serdang, Selangor Darul Ehsan
Malaysia

A.A. Zaharin
Environmental Forensics Research Centre
Faculty of Environmental Studies
Universiti Putra Malaysia
43400 Serdang, Selangor Darul Ehsan
Malaysia

A.N. Ainuddin
Institute of Tropical Forest and Forest Product
Universiti Putra Malaysia
43400 Serdang, Selangor Darul Ehsan
Malaysia

*Corresponding author; email: amakmom@upm.edu.my

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