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Soil Carbon Dioxide Efflux and Atmospheric Impact in a 10-Year-Old *Dipterocarpus* Recovering Lowland Tropical Forest, Peninsular Malaysia

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Abstract: The recovering logged-over forest ecosystem increases the CO_2 efflux into the atmospheric carbon pool in response to environmental factors to changes in the soil temperature and moisture. These CO_2 outbursts can have a marked influence on the ecosystem carbon balance and thereby affect the atmospheric carbon pool. The study was conducted in the 10-year-old logged-over forest of Sungai Menyala forest, Port Dickson, Negeri Sembilan, Malaysia. The measurements of soil CO_2 efflux were conducted using the continuous open flow chamber technique connected to a multi gas-handling unit and infrared CO_2/H_2O gas analyser. The aim of this study was to determine the soil CO_2 efflux and the environmental variables and likewise the impact of environmental factors on soil CO_2 efflux. Post-hoc comparisons were made using the Tukey test ($p < 0.05$), and multiple linear regression to determine the impact of environmental factors on soil CO_2 efflux. Soil CO_2 efflux ranged from 100.22-553.40 mg m^{-2} h^{-1} with the highest efflux in the afternoon attributed to an increase in soil temperature and low moisture. A higher soil temperature and low moisture signify an influential factor as the forest is recovering from logging activity. Furthermore, the predictor environmental variables: SOC (soil organic carbon), TOC (total organic carbon), SMC (soil moisture content), Bulk Density, SOCstock (soil organic carbon stock), TAGB (total above ground carbon biomass), Below Ground Carbon Biomass, soil pH, Nitrogen to Carbon ratio account for the spatial and temporal variation in soil CO_2 efflux into the atmosphere. The analysis revealed a strong correlation between soil CO_2 efflux, changes soil properties and environmental factors with an R^2 more than 0.80 at $p < 0.01$. This is proven that logging activity accounts for the changes in environmental factors to influence soil CO_2 efflux rate within 10-years of logging and forest recovering.

Key words: Biomass, forest ecosystem, carbon pool, carbon sink and soil CO_2 efflux.

1. Introduction

An increase in the greenhouse gas from the oceanic, terrestrial and atmospheric carbon pool has been considered to be a major contributor to global warming as well as climatic change [1]. However, among the deforested areas of the terrestrial ecosystems, recovering forests are considered to emit a high rate of soil CO_2 (carbon dioxide) to the atmosphere [2]. The soil emission of CO_2 into the atmosphere carbon pool is referred to as carbon efflux and has been estimated to comprise about 50-80% of the terrestrial ecosystem respiration [3, 4], with a total of 60-80 Pg carbon annually [5]. The factors responsible for soil CO_2 efflux are root and microbial activities. Roots are found to contribute 10 to 90% of respiration to the soil respiration, which varies across forest age, climatic condition and vegetation type [6, 7], while the litter decomposition and microbial metabolic activities to contribute to soil respiration are attributed to microbes. All the biotic and abiotic factors in various forests are affected by soil moisture, soil temperature, carbon to nitrogen, soil organic carbon, total above and below biomass, carbon stock, soil pH, forest type and age and soil type [8-10]. The changes from these environmental factors due to logging activity may strongly affect the spatial and temporal variations in soil CO_2 efflux. As a result of this logging, quantifying the associated environmental factors to influence soil CO_2 efflux is the key to estimate the soil CO_2 efflux rate. The mechanistic links of logging activity, environmental factors, soil properties and soil CO_2 efflux are poorly understood under the tropical deforested tropical forest [11], and the important step is to determine their interactive links and effect.

Recovering forests resulting from deforestation have been found to have great implications on the atmospheric carbon pool by contributing a high percentage of CO_2 compared to undisturbed forest ecosystems [12, 13]. The effect of deforestation will displace the aboveground biomass, in which the forest ecosystem serves as a carbon sink and carbon assimilation via photosynthesis results in the efflux of CO_2 into the atmospheric carbon pool [14]. This action will result in unexpected changes to the physiological activity, microbial activity, litter fall input and root density, thereby increasing the efflux of soil CO_2 into the atmosphere as result of changes in the temperature and the decay of fine roots [6]. The important aspect is the understanding both environmental and biological factors responsible for soil CO_2 efflux due to several years of deforestation activity and forest recovering under the tropical climate. The spatial and temporal variation in recovering logged-over forest will have many implications on the increase in soil CO_2 efflux in the atmospheric carbon pool as previous studies which have identified soil disturbance from logging could have an impact on soil CO_2 efflux [15]. Therefore, understanding the effect of logging activity and its influence on environmental factors is a crucial challenge and to curtail any increase in atmospheric CO_2 and forest management, detailed investigation concerning the change in environmental controlling factors and soil CO_2 efflux is paramount for the management of the tropical *Dipterocarpus* lowland forest ecosystem. Few studies have been documented concerning the impact of recovering logged-over *Dipterocarpus* lowland tropical forest in Peninsular Malaysia and the implications thereof on the atmospheric carbon. The aim of this study was to determine the soil CO_2 efflux and the environmental variables and likewise the impact of environmental factors on soil CO_2 efflux. This includes, the investigation of variation in environmental factors, soil properties and predictors to soil CO_2 efflux rate in the recovering 10-year-old forest and its contribution to the atmospheric carbon pool and the implications thereof.

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2. Materials and Methods

2.1 Site Description

Field experiments were conducted from 1st February to 30th June 2013, in the 10-year-old recovering Dipterocarp forest of Sungai Menyala (27°41′33″ N, 43°60′74″ E). The reserve forest is an extension forest for Seremban forest reserve. The study area is approximately 93.1 km from Kuala Lumpur. The forest reserve experiences equatorial climatic conditions with a temperature range of 23.7-32 °C and relative humidity of 59-96%, with an average of 83% and monthly rainfall of 200 mm [16]. While average solar radiation was 17.00 MJ M^{-2} and the daily evaporation rate was 3.1 mm day^{-1} [17]. The soil was classified as the Serdang-Kedah developed over mixed sedimentary rocks with a combination of local alluvium colluvium resulting from metamorphic rock [18, 19]. An experimental plot of 100 × 100 m with replicates was designed for the field experiment. The duration of the study represents the three seasons of the tropics (post-monsoon, pre-monsoon and monsoon period).

2.2 Measurement of Soil CO_2 Efflux and Environmental Variables

2.2.1 Measurement of Soil CO_2 Efflux

Soil CO_2 efflux was measured each day from 800 hours to 1,700 hours from 1st February to 30th June 2013, using two continuous open flow chambers of 64 cm in height and 50 cm width, with a volume of 3,250 cm^3 and an enclosed soil surface area of 2,500 cm^2 to reduce the build-up of pressure on the soil interphase, and monitored with a barometer [11]. The infrared gas analyser was calibrated in the laboratory using CO_2 as zero standards (1,000 g). The chambers were placed on soil collars, with a 3 cm thick closed foam gasket to prevent leakage from the chamber base as described by Ref. [11]. The soil collars were also inserted 3 cm into the soil for 24 hours before measurement for soil CO_2 to create an equilibrium stage. The measurement chambers were 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 (LiCor 6262), and, finally, to a computer system. Soil CO_2 efflux was recorded every 5 sec over a period of 5 min for each chamber, from which an average was calculated to estimate the soil CO_2 concentration for 5 min for each chamber.

2.2.2 Soil Temperature, Soil Moisture and Soil Water Potential

Soil temperature, soil moisture and soil water potential were measured at a depth of 5 cm at intervals of 5 min concurrently with each soil CO_2 chamber reading using soil temperature, 4 moisture probes and water potential probes (Watchdog data logger model 125 spectrum technology, TDR Trime FM and Delmorst model KS-D1), respectively. These measurements were conducted concurrently with soil CO_2 efflux to establish their linear relationship.

2.2.3 Carbon, Nitrogen Input by Litter Fall and LAI (Leaf Area Index)

To ascertain light intensity distribution and forest canopy stand density, this was based on LAI using a sunfleck ceptometer (AccuPAR model sf-80, Decagon, Pullman, WA), measuring a total of 630 trees in the study plots. Ten litter trap nets per plot were placed 1 m above the forest floor for the collection of leaves at 14-day intervals for five months to ascertain the Carbon to Nitrogen ratio. The litter collected from each trap was transported to a laboratory and oven-dried at 65 °C for 48 h. All dried samples were separated into needle, bark, cones brances and miscellaneous components, and each component was weighed. The C/N ratio concentration was determined using a TruMac Macro Analyzer (Leco-Corp), while the mass loss rates in the needle litter were estimate using the litterbag technique [20].

2.2.4 Total Aboveground Biomass, Total Belowground Biomass, Soil and Total Forest Carbon Stock

Forest biomass was estimated using the allometric relationships obtained in the forest according to the International Biological Programme [21]. The TAGB (total above ground biomass) was determined by measuring the DBH (diameter at breast height) of about 930 trees in the confirmed plot [22], all the trees >5 cm in DBH were identified, tagged and their DBH was measured just above the buttresses [23]. The DBH was measured using the DBH tape, 1.3 m above the forest floor for each tree, and the TAGB was estimated using the model of Ref. [24]. The model estimates the tree stem, branch and leaf biomass. These components form the TAGB based on the simple regression lines fitted for DBH and tree height:

$$Tree\ height\ (H)\frac{1}{H} = \frac{1}{(a.D)} + \frac{1}{MaxHt} \quad (1)$$

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 > 4.5 cm.

Weight (kg) of main stem (Ws):

$$Ws = 0.313(D^2 \quad H)^{0.9733} \quad (2)$$

Weight (kg) of branches (Wb):

$$Wb = 0.313 \quad (3)$$

Weight (kg) of leaves (Wl):

$$\frac{1}{Wl} = \frac{1}{(0.124.Ws^{0.794})} + \frac{1}{125} \quad (4)$$

TAGB was calculated as:

$$TAGB = Ws + Wb + Wl \quad (5)$$

The Below Ground Carbon Biomass was calculated using the model of Ref. [25]:

$$Root\ (W_R) = 0.0264\ (D^2H)^{0.775} \quad (6)$$

The total forest carbon stock was estimated based on the carbon content in the biomass data. The default value for the carbon content on biomass is 0.47 [26], which varies among different countries; it was calculated as:

$$C_b = B\ x\ \%\ C\ organic \quad (7)$$

where, Cb is the carbon content from the biomass, B is the total biomass, *% C organic* is the percentage value for carbon content, amounting to 0.47 default value or laboratory obtained value.

2.2.5 Soil Sampling and Analysis

Soil samples were taken randomly at three sampling points of each plot from a depth of 0-100 cm. The soil samples were weighed, air dried and oven dried at 105 °C for 48 hours to determine the soil water content (mass basis) [27]. The standard method was used to analyse for SOC, SMC, bulk density and soil pH according to the Kjeldahl method [28], while the Walkley Black method was used to determine the TOC [29]. The SOCstock (soil organic carbon stock) was estimated using the model of Ref. [30], with the given depth of top soil from 0 to 100 cm. The soil moisture content was estimated using the standard method based on the following equation [29].

$$Moist\ (wt\%) = \left[\frac{(A-B)}{B - tare\ tin}\right] x\ 100 \quad (8)$$

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

$$Moist\ corection\ factor = {(100 + \ \%\ moist)}/{100} \quad (9)$$

where, A is the mass of moist soil (g), B is the mass of oven dry soil (g).

The bulk density was estimated in accordance with the standard method [31]:

$$Bulk\ density\ (mgm^{-3}) = {g}/{v} \quad (10)$$

where: g = oven dry mass of the sieve soil (g), v = sample volume (cm^{-3}).

SOC was determined based on the following equation:

$$M = {10}/{Vblank} \quad (11)$$

$$\%oxidizable\ organic\ carbon\ ({W}/{W}) = {[V\ blank - V\ sample]}/{Wt}\ x\ 0.3\ x\ mass \quad (12)$$

$$\%total\ organic\ carbon\ ({W}/{W}) = 1.334\ x\ \%\ oxidazable\ organic\ carbon \quad (13)$$

$$\%organic\ matter\ ({W}/{W}) = 1.724\ x\ \%total\ organic\ carbon] \quad (14)$$

where,

M = molarities of ferrous ammonium sulphate solution (app 0.5 cm^{-3}),

V_{blank} = volume of ferrous ammonium sulphate solution required to titrate the blank (cm^{-1}),

Wt = weight of air dry soil (g)0.3 = 3 × 10^{-3} × 100 where 3 is the equivalent weight of C.

The TOC was determined by the Walkley-Black method using a correction factor of 1.33 [29], as it is appropriate for moisture analyses because of its simplicity.

$$Toc\ (\%c) = M\ x\ \left[{}^{(V1 - V2)}/_{S}\right] x\ 0.39\ x\ mcf \qquad (15)$$

where,

M = molarities of ferrous sulphate solution (from blank titration),

V_1 is the cm^{-3} ferrous sulphate solution required for blank,

V_2 is the cm^{-3} ferrous sulphate solution required for S = weight of air dry sample in grams,

mcf is the 3 (equivalent weight of carbon) corrected factor.

Soil Carbon Stock using the model of Ref. [30], where the given depth of soil was from 0 to 100 cm. SOC based on the compacted soil was estimated by determining the *BD*. The equation is expressed as:

$$SOC_{stock} = \frac{SOC\ content\ of\ the\ soil\ x\ BD\ x\ area\ x\ depth}{10} \qquad (16)$$

2.3 Statistical Analysis

To establish the attribution of logging and recovering forest influence on environmental factors to soil CO_2 efflux in the 10-year-old recovering logged-over forest, data were subjected to statistical analysis using SPSS software (SPSS Inc., Chicago, Illinois, USA) version 21.0. Repeated measures analysis using one-way ANOVA (analysis of variance) to present the means and standard deviation of soil CO_2 efflux and environmental factors [32, 33]. Likewise the Post-hoc Dunn's test and Tukey test ($p <$ 0.05) comparison was used. The descriptive statistic was also used to explain the normality of data distribution and to quantify the correlation between forest biomass, soil properties and environmental factors. The multiple linear regression model was employed to ascertain the impact of the environmental factors from the recovering forest on soil CO_2 efflux. The techniques were used for both predictive and explanatory purposes within the experimental design, as it can be expressed as:

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

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

3. Results

3.1 Soil CO_2 Efflux and Environmental Factors

Based on the hourly and daily soil temperature and moisture changes, it was observed that soil CO_2 efflux varies significantly. The efflux rate was found to range from 104.82 to 271.39, 100.22 to 372.99, 102.37 to 454.68, 104.42 to 370.32 and 107.17 to 553.40 mg m^{-2} h^{-1}, for February, March, April, May and June, respectively (Table 1 and Fig. 1). There was significant difference ($p < 0.01$) between the average mean of soil CO_2 efflux in the months of measurement, and minimum and maximum efflux rate was between 100.22 and 553.40 mg m^{-2} h^{-1} (Table 1). The low efflux occurred in the morning hours of 08:00 to 11:00 h and an instantaneous high efflux rate occurred between 13:00 and 15:00 h. Significant ($p < 0.01$) higher values were recorded in the month of April and June, closely followed by March and May with lower efflux experienced in February, showing a variation in the flux pattern. The corresponding values for soil temperature, soil moisture and water potential in 5 cm soil depth fluctuated across the five months of the research, 24.01-26.87 °C, 20.43-26.59% and 96.6-97.6%, respectively. Soil CO_2 efflux obviously varied at

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	72	205.92	55.24	6.51	192.93	218.10	104.82	271.39
March	72	278.81	141.17	16.64	245.64	311.99	107.17	553.40
April	72	255.23	94.25	11.11	233.08	277.37	102.37	454.68
May	72	226.33	86.71	10.22	205.95	246.70	100.22	372.99
June	72	217.19	71.91	8.47	200.29	234.09	104.42	370.32
Total	360	236.69	97.59	5.14	226.58	246.81	100.22	553.40

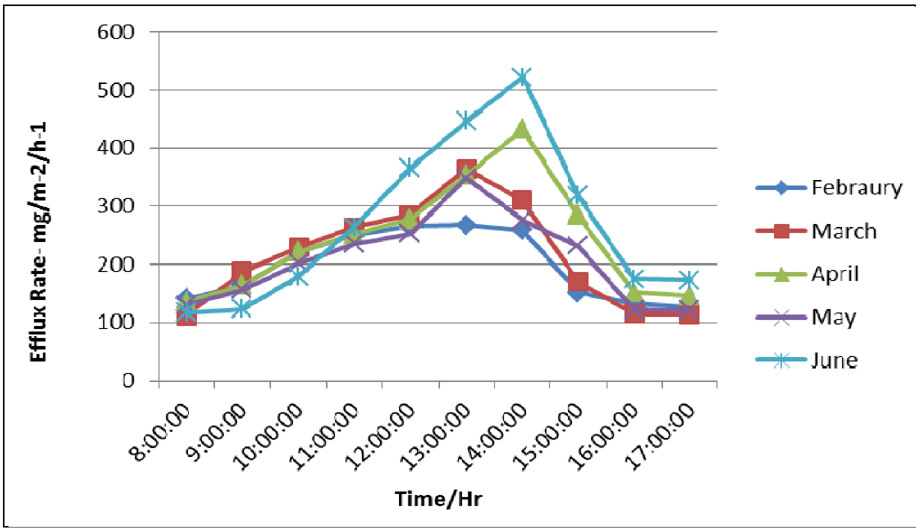

Fig. 1 Soil CO_2 efflux trend across five months.

different months, as analysis of variance signify changes environmental factors as the forest is recovering due to logging significantly affected soil CO_2 efflux. Furthermore, correlation analysis showed that soil CO_2 efflux was more correlated with increasing soil temperature at 0.89, $p < 0.01$ compared to soil moisture and water potential at 0.76, $p < 0.01$. This suggests that soil temperature controls the variation in soil CO_2 efflux due to variation in time and period in relation to microclimate condition as the forest canopy is open. Furthermore, the multiple regression model revealed a strong correlation at R^2 = 0.73, 0.76, 0.78, 0.85 and 0.89 between February and June, and this relationship is equally at different months.

3.2 Bulk Density, TOC, SOC, Soil Moisture Content and pH

Soil properties from the recovering forest in terms of bulk density were found to fluctuate and increased with soil depth between 0 and 100 cm given good porosity for water movement and cation exchange capacity to hold onto nutrients suitable for microbial activity (Fig. 2). The physiochemical parameter recorded from the analysed soil showed that the soil contained TOC and SOC of 4.6% and 4.9%, respectively (Table 2). Soil moisture content occurred at 37.39% and a corrective factor of 1.37 (Table 2), responsible for soil nutrients. The high soil temperature is being influenced by the open canopy density as the trees are young, subsequently soil temperature influenced both the forest carbon input and soil properties as they were positively and strongly related to soil CO_2 efflux (R^2 = 0.73 - 0.89). The soil pH was found to be slightly acidic at 5.55 (Table 2). In addition, carbon and nitrogen input from litter fall contribute about 42.92% and 1.16%, respectively (Table 2), which is responsible for the organic matter decomposition.

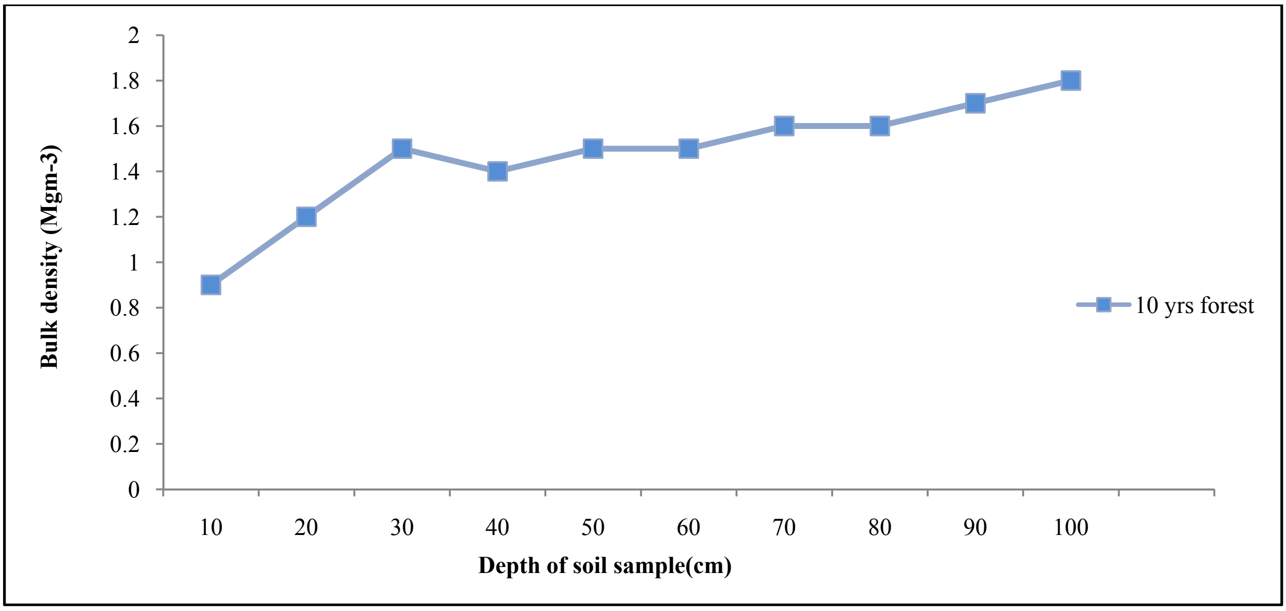

Fig. 2 Behaviour of bulk density with soil depth.

Table 2 Analysis of soil sample, litter fall and trees stand density.

ECOSYSTEM	SOC %	TOC %	pH	Soil moisture content %	Moisture correction factor	Litter falls Carbon %	Litter falls Nitrogen %	SOCstock Mg/ha	TAGB kg	BGB kg	SOCs kg
TEN YEARS FOREST	4.93	4.6	5.67	37.39	1.37	47.92 - 50.85	1.29 - 1.48	59.1	992346.2	44698.25	4874109

SOCstock = soil organic carbon stock, TAGB = total above ground biomass, BGD = total below ground biomass, SOCs = total forest carbon stock.

3.3 Total above Ground Biomass, Total below Ground Biomass, Total Forest Carbon Stock, Soil Organic Carbon Stock and Litter Fall

The 10-year-old recovering lowland forest spatial and temporal variation of soil efflux CO_2 is related to the biophysical and environmental conditions resulting from the high amount of total above ground biomass, total belowground biomass and total forest carbon of 9.9×10^6 kg, 4.5×10^5 kg and 4.9×10^6 kg, respectively (Table 2), as reported by Ref. [34]. Also, the estimated soil carbon stock in the top 100 cm was 59.1 mg ha^{-1} (Table 2) and the average carbon and nitrogen input for the entire study period ranged between 47.92 and 50.85%, 1.29 and 1.48%, respectively (Table 2). These indicated a high amount of nutrients for microbial activity.

4. Discussion

4.1 Soil CO_2 Efflux

The one-way ANOVA statistical value was considered significant when the *p* value was less than 0.05 ($p < 0.05$). A post-hoc test across the five months indicated a significant difference at 0.001 ($p < 0.01$), and the normality of distribution aligned along the straight line without any outlier giving good skewness (Fig. 3).

Soil CO_2 efflux in the recovering forest ecosystem was found to vary significantly in response to environmental factors and change soil properties, likewise was attributed to forest carbon input. The average lower soil CO_2 efflux from the five months of measurement was 100.22 mg m^{-2} h^{-1}, which is similar to that of the subtropical forest of China [35] and

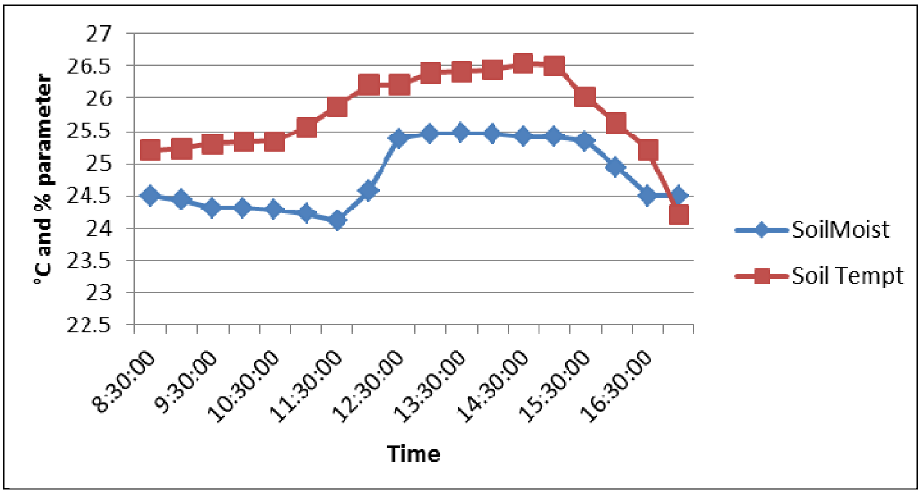

Fig. 3 Average soil temperature and moisture increase with time.

highest at 553.40 mg m^{-2} h^{-1}, which is similar to the canopy cover tropical spare forest of China of about 730.8 mg m^{-2} h^{-1} [36]. The average soil respiration in the month of February was found to range between 1,004.82 and 271.39 mg m^{-2} h^{-1}, similar to the Leymus chinensis steppes in Inner Mongolia [37], with a steady increase between 100.22 and 372.99 mg m^{-2} h^{-1} in March. The soil CO_2 efflux increased more in April than March, between 102.37 and 454.68 mg m^{-2} h^{-1} or the same range as the tropical forest in China [37]. A relatively lower emission of 104.42-370.32 mg m^{-2} h^{-1} was recorded in May, which is similar to the 11-307 mg m^{-2} h^{-1} experimental field of Hokkaido University [38]. June displaced the highest soil respiration efflux of 107.17-553.40 mg m^{-2} h^{-1}, greater than the canopy field woodland of northern China [37], which was strongly influenced by soil temperature and was significant corrected ($p < 0.01$). An increase in soil CO_2 efflux across the day was recorded, with the highest values in the afternoon coinciding with the maximum daily soil temperatures of the day. However, there were significant differences in the total daily efflux between the early months and mid months of the year.

4.2 Effect of Soil Moisture, Soil Temperature and Water Potential Impact

Soil CO_2 efflux and environmental factors variation pattern show to be dependable during the period of measurement. The multiple regression model was used to explain the spatial and temporal variation of the soil CO_2 efflux in respect of soil temperature and moisture since it provided a better fit of coefficient (R^2). The month of February showed a beta coefficient of 0.708 and -1.100 for soil temperature and moisture, respectively (Table 3), suggesting a significant impact ($p < 0.01$) soil CO_2 efflux from soil temperature compare to soil moisture. While in March, the impact of soil temperature and moisture was recorded as 0.875 and -1.011, respectively (Table 4), indicated that soil temperature and moisture accounted for a significant effect in the soil CO_2 efflux ($p < 0.01$). The month of April displaced the soil temperature and moisture impact on soil CO_2 efflux at 0.388 and -0.613, respectively (Table 4). Soil CO_2 efflux was in response to increase in soil temperature and moisture as it was observed in the month of May to displace a beta coefficient of soil temperature and moisture on soil CO_2 efflux at 0.699 and 0.561, respectively (Table 6). The month of June showed a beta coefficient of 0.860 and -0.687 for soil temperature and moisture, respectively (Table 7), suggested a significant impact ($p < 0.01$) from soil temperature, as soil moisture was at a constant level. Correlation analysis indicated a strong to moderate relationship between the soil CO_2 efflux and soil temperature and moisture (Table 8). The soil temperature, moisture and water potential varied across the day, for the period of the five months from relatively high in the morning to very high in the afternoon and decreasing over time (Figs. 4 and 5). This suggested that soil temperature-moisture and water potential interaction explained the spatial and temporal variation of soil CO_2 efflux [39].

Table 3 Ten 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
	(Constant)	16,390.29	1,493.92		10.97	.000		
1	FEBSTempt	57.89	8.32	.71	6.96	.000	.519	1.929
	FEBSMT	-672.74	62.21	-1.10	-10.81	.000	.519	1.929

a. Dependent variable: February CO_2. FEBSTempt = February soil temperature, FEBSMT = February soil moisture.

Table 4 Ten 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 Tolerance
		B	Std.Error				
	(Constant)	269.02	408.64		.66	.51	
1	MarST	151.50	24.16	.88	6.27	.00	.42
	MarSMT	-159.84	22.06	-1.01	-7.25	.00	.42

a. Dependent variable: March CO_2. MarST = March soil temperature, MarSMT = March soil moisture.

Table 5 Ten 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 Beta	t	Sig.	Collinearity Statistics	
		B	Std. error				Tolerance	VIF
	(Constant)	21,281.87	3,443.71		6.18	.00		
1	AprST	69.46	16.91	.39	4.11	.00	.95	1.05
	AprSMT	-1,112.36	171.42	-.61	-6.49	.00	.95	1.06

a. Dependent variable: April CO_2. ApriST = April soil temperature, ApriSMT = April soil moisture.

Table 6 Ten 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 Beta	t	Sig.	Collinearity Statistics	
		B	Std. error				Tolerance	VIF
	(Constant)	-4,350.41	534.59		-8.14	.00		
1	MayST	74.96	9.27	.70	8.08	.00	.89	1.13
	MaySMT	101.65	15.66	.56	6.49	.00	.89	1.13

a. Dependent variable: May CO_2. MayST = May soil temperature, MaySMT = May soil moisture.

Table 7 Ten 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 Beta	t	Sig.	Collinearity Statistics	
		B	Std. error				Tolerance	VIF
	(Constant)	-612.81	457.86		-1.34	.19		
1	JunST	181.30	17.14	.86	10.58	.00	.77	1.30
	JunSMT	-148.54	17.57	-.69	-8.46	.00	.77	1.30

a. Dependent variable: June CO_2. JunST = June soil temperature, JuneSMT = June soil moisture.

Table 8 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	.79	.62	43.08	58.75	< 0.001
March	.66	.42	65.92	26.92	< 0.001
April	.65	.42	72.10	24.69	< 0.001
May	.74	.53	49.38	40.77	< 0.001
June	.81	.64	84.98	63.47	< 0.001

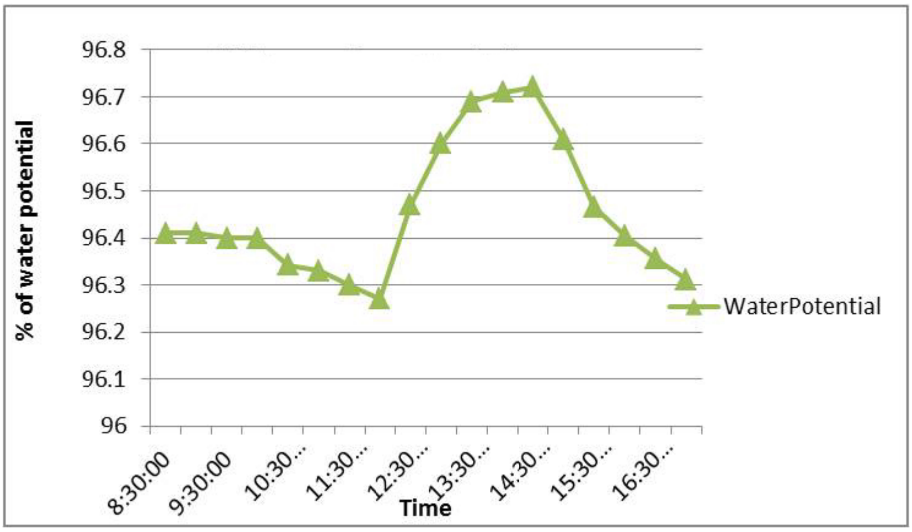

Fig. 4 Average water potential in a ten years recovering forest.

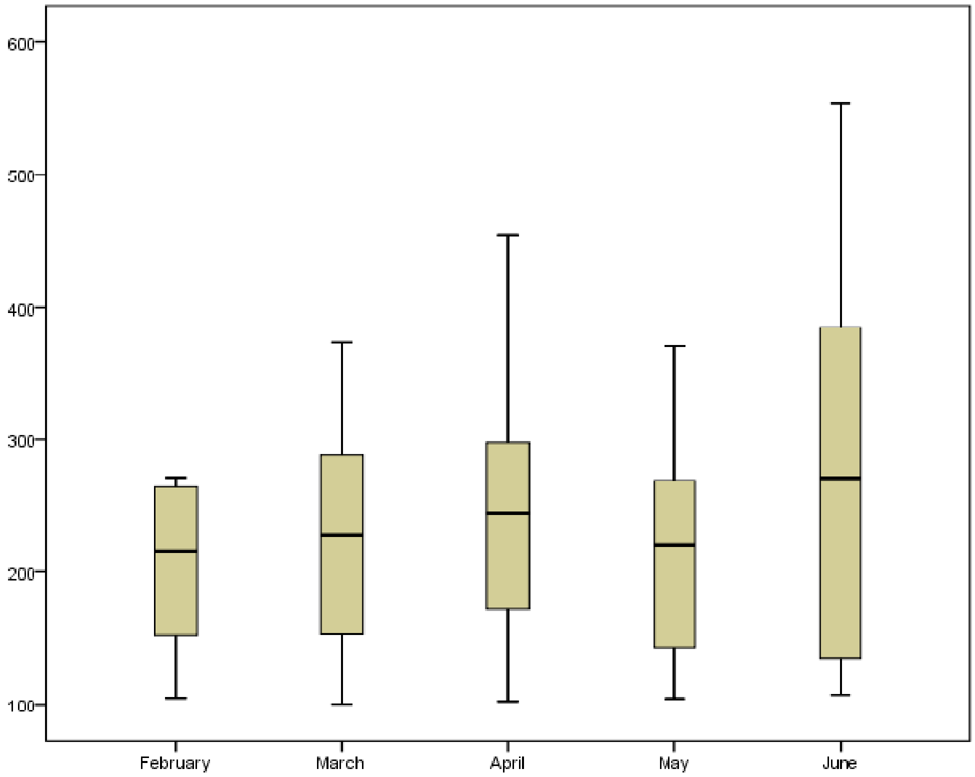

Fig. 5 Box and whisker plot of environmental parameters.

4.3 Influence of Soil Properties

A soil CO_2 efflux ranges from 100.22 to 553 mg m^{-2} h^{-1} across the five months was found to correspond to the increase in TOC, SOC, soil moisture content, water potential of 4.6%, 4.925%, 20.43-26.57, 94.7-96.71% respectively and slight acidity soil of 5.67, as was also reported by Ref. [40]. The increase in bulk density with depth indicated the role of pore space played in water movement, electrical conductivity and microbial activity. The overall input from the soil properties resulting from forest biomass increases nutrient in the soil as source of food and energy for microbial activities as they respire in the process of decomposition of soil organic matter, serving as a prime factor to emit a considerable amount of soil CO_2 [41]. However, soil properties increase as the forest recovers [42].

4.4 Input from Litter Fall (C:N), TAGB, BGB, SOCstock and SOCs

The carbon to nitrogen input for the five months was significantly ($p < 0.01$), which ranged from 47.92 to 50.85% and 1.29 to 1.48%, respectively, was related to the canopy stand density based on the age of the forest [43], which served as nitrate for the lignin and microbial activity, and was attributed to the soil respiration. This further explains the monthly variation in soil respiration of the 10-year-old forest [44]. The greater percentage for Total Above Ground, Below Ground Biomass, Soil Carbon Stock and Total Forest Carbon Stock suggests the significant role played by the biomass and carbon, which was a major predictor of the spatial and temporal variation across the five months of soil CO_2 efflux measurement. Therefore the soil properties were found to have a significant relationship with soil CO_2 efflux across the 10-year-old Dipterocarp recovering forest.

In general, the combined interaction between soil properties, forest biomass and changes environmental factors as the forest recover are the key factors that affect the variation and significant CO_2 efflux rate [45, 46]. This study revealed a strong correlation between the factors similar the study conducted by Ref. [47]. The Pearson correlation and multiple regression analysis indicated significant different ($p < 0.01$), as the strength of association between the various factors and confirmed that soil temperature was the leading factors compared to the other environmental factors. This suggested that soil temperature played a dominant role, as it can increase the physiological activity of soil microorganism, leading to higher decomposition rate and higher soil CO_2 efflux. When other factors were added to the analysis, it was found that soil CO_2 efflux was strongly positively correlated ($p < 0.01$).

5. Conclusion

The multiple linear regression model was used, in which the classical assumption for linear regression comprising the check and collinearity diagnostic, showed that none of the conditional index models for the five months of study period were above the threshold limit of 30.0. In addition, none of the tolerance values were less than 0.10, indicating that no multicollinearity problems existed among the variables of the models. With this condition met, it is reasonable to conclude that the estimated multiple linear regression model can be used to explain the impact of soil temperature, moisture and water potential on soil CO_2 efflux and the overall CO_2 efflux into the atmosphere due to deforestation. To establish the attribution of the environmental factors to soil CO_2 efflux and recovering 10-year-old forest, statistical correlation was employed, which indicated that the contribution of the environmental factors to total soil CO_2 efflux varies with months, and any increase in the soil temperature, moisture or water potential would affect the soil CO_2 efflux. Furthermore, the high correlation between the soil carbon input, total biomass, TOC, SOC, C/N, soil pH, bulk density and the interaction among the environmental factor influences soil CO_2 efflux resulted in a high efflux rate from the 10-year-old Dipterocarp forest, as was indicated by the multiple linear regression model, as well as the descriptive and correlation statistical analysis at strong relationship ($R^2 = 0.87$, p = <0.01). This result suggests that the monthly soil CO_2 efflux is not just the function of soil temperature and moisture but also of the litter fall pulses and drying and rewetting cycles, as indicated by the Beta coefficient relationship as the forest is recovering due to logging activity. Therefore, considerable amount of soil CO_2 efflux is being emitted into the atmosphere without much percentage stored in the forest due to the reduced forest canopy. Therefore, the negative impact resulting from this scenario is the increased emission of CO_2 into the atmospheric carbon pool, due to the reduced forest canopy to capture CO_2 for photosynthesis and also to serve as a carbon sink. It is conclusive that recovering forest resulting from deforestation spills a considerable amount of CO_2 into the atmospheric carbon pool, thereby altering the carbon balance.

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