

Emission of CO₂ from Soil in a Subtropical Mixed Oak Forest of Manipur, Northeastern India

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ABSTRACT

Emission of CO₂ from soil and the effect of abiotic variables on the rate of soil respiration were studied in two forest stands of a subtropical mixed oak forest in the Langol Hills (24° 45' N; and 93° 55' E; at altitudes from 780 to 910 m above msl) using alkali absorption method. The CO₂ emission rate was the lowest in winter (November–February; 149±4.82 mg CO₂ m⁻² hr⁻¹; 138.49±3.3 mg CO₂ m⁻² hr⁻¹) and the highest in the rainy season (June–October; 250.94±5.64 mg CO₂ m⁻² hr⁻¹; 220.48±7.8 mg CO₂ m⁻² hr⁻¹) in both study stands. This paper demonstrates that soil emission of CO₂ is strongly influenced by seasons and it has been correlated positively with the measured abiotic variables.

Key Words: Emission, Forest soil, Manipur, Seasons, Abiotic variables.

INTRODUCTION

Soil surface carbon dioxide i.e., the output of soil respiration, exceeds all other terrestrial atmospheric carbon exchanges except for the volume of the output of gross photosynthesis (Raich and Schlesinger 1992). Almost 10% of atmosphere's CO₂ passes through soil each year, which is more than 10 times the CO₂ released from fossil fuel combustion. Due to the magnitude of this soil to atmospheric CO₂ flux and the large pool of potentially mineralizable C in soils, any increase in soil CO₂ emissions in response to environmental change has the potential to exacerbate increasing CO₂ levels in the atmosphere and to provide a positive feedback to global warming. However, in geoformations such as the poles and high elevations, there will be local cooling effect due to melting of ice from glaciers leading to floods in the plains and subsequent water shortage in the future (Singh et al. 2006). Therefore, identifying the environmental factors that regulate soil CO₂ emissions and the effects of those factors on CO₂ emission rates is a necessary step in assessing the potential impacts of environmental change. Seasonal changes in soil microclimate play a key role in defining seasonal differences in soil – CO₂

emissions within sites and climatic differences generate different soil respiration rates among distant sites (Raich and Potter 1995).

Limited information is currently available on annual soil CO₂ flux from India (Singh and Gupta 1977, Tewary et al. 1982,) and especially from north-eastern India (Laishram et al. 2002). Therefore, the present study aims to evaluate (i) the monthly and seasonal soil CO₂ fluxes and (ii) the effects of abiotic factors on soil respiration rate in a subtropical mixed oak forest ecosystem of Manipur.

MATERIALS AND METHODS

The study site is located in the Langol Hills, situated at a distance of 7 km from Imphal city (24°45'N; 93°55'E) at altitudes 780–910 m amsl. Climate at the site is monsoonal with warm moist summers (March–May), rainy (June–October) and winter (November–February). The mean monthly maximum temperatures range from 24.3 to 32.7°C and mean monthly minimum temperatures range from 3.2 to 21.1°C. Average annual rainfall is 1089.75 mm with 68–70% of rains occurring in June–October (Figure 1).

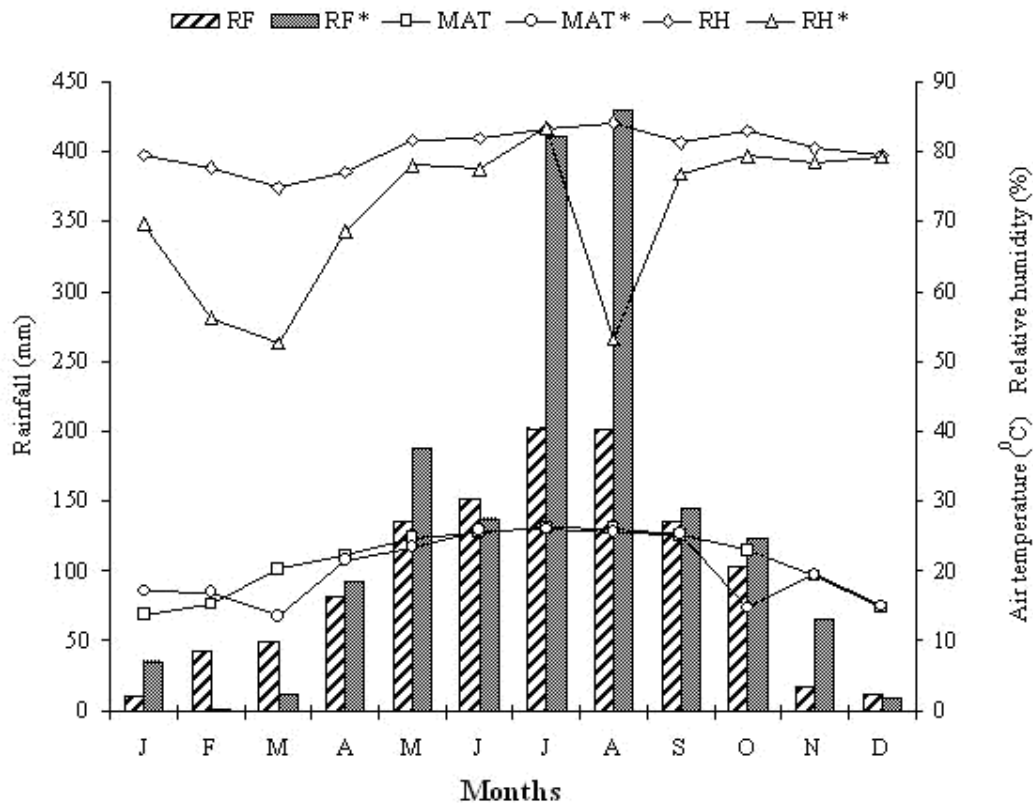


Figure 1. Climatological data of the study site during the study period (2002) and in the context of 1993–2002 timeframe. RF – mean monthly rainfall, MAT – mean air temperature, RH – mean relative humidity (1993–2002). RF* – rainfall, MAT* –air temperature, RH* – relative humidity. (Source: Meteorological station, Imphal Airport)

The present study was conducted in two stands (hereafter, Stands I and II). Stand I occurs at the foot of the hill and is dominated by *Quercus serrata* and *Schima wallichii* (density of *Q. serrata* is 9.20 per 100 m² and of *S. wallichii* is 9.10 per 100 m²); it remains exposed to sun for a short period in the morning hours (hardly two hours), whereas Stand II, at the top of the hill is dominated by *Q. serrata* and *Lithocarpus dealbata* (density of *Q. serrata* is 9.3 per 100 m² and *L. dealbata* is 8.9 per 100 m²) and is exposed to sun directly throughout the day (about 12 hours). The soil is silty loamy in Stand I and loamy in Stand II and the parent material derived from shale and sandstone in the present study site (Singh et al. 2006).

Soil respiration rate was measured by alkali absorption method (Anderson 1982) using open-ended cylinders (13 cm dia; 25 cm tall), which were inserted into the soil up to 15 cm depth. Six identical cylinders were used in each of the Stands. Fifty ml of 0.25N NaOH solution in each cylinder was maintained for 24 h and all green vegetation inside the cylinder was

removed. After 24 h the alkali was titrated with 0.25N HCl solution using phenolphthalein as an indicator. CO₂ absorbed from the soil was calculated using the formula proposed by Anderson and Ingram (1993): $V \times N \times 22 = \text{CO}_2 \text{ mg}$, where V = volume of HCl, N = normality of HCl. Soil texture was analyzed by pipette method following Gee and Bauder (1986). A soil thermometer (Lanxi™, RMT-150, Changzhou Ruiming Thermometer Factory, Jiangsu, China) was used to determine soil temperature. The soil moisture was measured by gravimetric method (oven dry at 105°C till constant weight). Soil pH (1:2.5 water suspension) was determined by a pH meter (Systronics: Type 323, Systronics India Limited, New Delhi, India). Soil organic C, total N, and total P were determined following methods proposed by Anderson and Ingram (1993), Bremner and Mulvaney (1982) and Sparling et al. (1985), respectively. The physico-chemical characteristics of soil were analyzed up to a depth of 10 cm. ANOVA was used to analyze the data.

RESULTS

In Stand I, the soil respiration rates ranged from 120.26 to 324.47 mg CO₂ m⁻² hr⁻¹. Minimum soil respiration rates were recorded in March, which increased consistently till August and thereafter decreased gradually till December (Table 1).

Table 1. Monthly variation of soil respiration rate (mg CO₂ m⁻² hr⁻¹ ± S.E) in Forest Stands I and II

Months	Forest Stand I	Forest Stand II
January	188.4±2.52	169.2±3.1
February	162.1±4.9	134.7±5.0
March	120.3±2.75	111.12±3.3
April	154.3±2.92	149.2±2.6
May	196.4±3.31	196.4±3.7
June	219.3±8.88	212.9±7.8
July	256.2±6.00	267.7±6.3
August	324.5±3.24	200.6±3.3
September	241.8±5.33	198.4±5.7
October	212.9±4.12	133.8±4.7
November	128.5±2.72	129.5±3.6
December	120.4±2.45	120.5±2.1

In Stand II, the rate of soil respiration ranged from 112.12 mg CO₂ m⁻² hr⁻¹ to 267.67 mg CO₂ m⁻² hr⁻¹ in different months throughout the year. Seasonally, soil respiration rate was the highest in the rainy season (June–October), followed by summer (March–May) and winter (November–February) (Table 1). An analysis of variance (ANOVA) indicated a significant difference in soil respiration rate between the different sampling months in summer (p<0.01), rainy (p<0.01), winter (p<0.01) periods, as well as annually (p<0.01).

The rate of soil respiration correlated significantly and positively with the abiotic factors, i.e. soil moisture, soil temperature, relative humidity, mean air temperature, and rainfall in Stands I and II (Table 2). The relationship between soil respiration rate (Y, mg CO₂ m⁻² hr⁻¹) and rainfall (X₂, mm) and temperature (X₃, °C) at the two stands can be summarized as follows:

Stand I:

$$Y_1 = 280.666 + 0.317X_2 + 2.14X_3$$

$$(r_1 = 0.867, r_2 = 0.718), p \leq 0.005$$

Stand II:

$$Y_2 = 29.989 + 0.111X_2 + 6.056X_3$$

$$(r_1 = 0.802, r_2 = 0.874), p \leq 0.005.$$

The soil was silty loamy with 51.6% sand, 13.3% clay and 22.7% silt in Stand I, whereas in Stand II it is loamy with 61.4% sand, 14.8% clay and 30.7% silt in both the stands. Soil moisture ranged from 24.74 to 28.34%, soil temperature ranged from 16.83 to 17.08°C, soil pH 4.2–6.1, soil organic carbon 2.6–4.4%, soil total N 0.33–0.54%, total P 0.042–0.082% and bulk density 1.38–1.46 g cm⁻³, C/N ratio varied from 7.0 to 8.7 across both stands (Table 3).

Table 2. Correlation co-efficients (r) for the relationship of soil respiration rate (CO₂ released) with the measured abiotic variables in two forest stands

Parameters	Stand I	Stand II
Soil moisture (%)	0.55*	0.51*
Soil temperature (°C)	0.82**	0.83**
Relative humidity (%)	0.56*	0.56*
Mean air temperature (°C)	0.72**	0.87**
Rainfall	0.87**	0.80*

NS – not significant; P<0.05; ** P<0.01

Table 3. Abiotic variables and physico-chemical characteristics of soils in Forest Stands I and II (up to 10 cm depth)

Abiotic variables	Stand I	Stand II
Soil temperature (°C)	16.83	17.08
Soil moisture (%)	28.34	24.74
Soil texture	Silty loam	Loam
Sand (%)	51.6	61.4
Silt (%)	30.7	22.7
Clay (%)	14.8	13.3
Bulk density (g cm ⁻³)	1.38±0.32	1.46±0.27
Soil pH	4.2–5.8	4.5–6.1
Soil organic C (%)	2.75–4.4	2.6–4.34
Soil total N (%)	0.39–0.54	0.33–0.50
Soil available P (%)	0.07–0.082	0.042–0.069
C:N ratio	7.0–8.1	7.8–8.7

DISCUSSION

The rate of soil respiration was minimum in March in both Stands, which may be due to the torrential rains in winter months resulting in a low moisture content of the soil, temperature, and relative humidity, thereby inhibiting the microbial activity and decomposition (Devi and Yadava 2006), thus leading to low CO₂ emission from the soil. However, maximum soil respiration rate in rainy months in Stands I (August) and II (July) coincided with a higher soil and air temperature, high soil moisture, and relative humidity favouring the activity of soil microbes leading to an enhancement of decomposition of litter materials, contributing to the released CO₂ from soil. The high soil respiration rate in the rainy season could be due to a congenial environment for the microorganisms in the soil and decomposing organic matter, contributing to CO₂ emission. Besides, the rate of decomposition of the litter materials has also been reported to be high in the rainy months (Devi 2005). In contrast, the cool and dry winter season decelerate decomposition and microbial activity, leading to CO₂ emission. The rate of CO₂ efflux was higher in Stand I than in Stand II, which may be due to the different microbial communities associated with different tree species, substrate quantity as determined by the quantity of litter (Devi 2005) and quality of litter as determined by the difference in nutrient concentration due to different tree species in the two evaluated stands (Devi 2005). Zhou et al. (2002) reported that microbial communities associated with species may vary and such variations could also affect soil respiration rate.

Several reports on high soil respiration rate in wet seasons exist (Kursar 1989, in a lowland moist forest of Panama; Rajvanshi and Gupta 1986, in tropical *Dalbergia sisoo* forest; Savage and Davidson 2001, in Harvard forests; Saraswathi et al. 2008, in a semi-arid soil of India), which are in conformity with our observations. Holt et al. (1990) and Law et al. (2001) have also reported an increase in soil respiration rate immediately after rainfall events. Most of the studies on soil respiration reported a maximum rate of soil respiration in either spring or early summer (Davidson et al. 2002, Laishram et al. 2002, Rastogi et al. 2002). However our results contradict their findings reporting a maximum in rainy months, which could be due to the activity of microbes releasing the air trapped in soil pores of dry soil contributing to an increase in CO₂ emission. The rate of CO₂ efflux in the oak forests of Manipur is within the range similar to that known in *Quercus-Carya*

stands of Missouri (115.64 mg CO₂ m⁻² hr⁻¹; Garrett and Cox 1973), in mixed oak-conifer forests of India (101.3–270.0 mg CO₂ m⁻² hr⁻¹; Tewary et al. 1982), in *Quercus prinus* forests of Tennessee (69.63 mg CO₂ m⁻² hr⁻¹; Edwards et al. 1989), and temperate forests of Manipur (368.00–634.23 mg CO₂ m⁻² hr⁻¹; Laishram et al. 2002).

A high correlation coefficient shows that the soil temperature, mean air temperature and rainfall have a significant and positive effect on soil respiration rate in both Stands whereas soil moisture and relative humidity have a positive relationship, but not significant. Several studies have reported that temperature was the single critical variable for predicting the soil CO₂ flux (Singh and Gupta 1977, Pandey and Singh 1981, Raich and Potter 1995, Bijracharya et al. 2000 and Saraswathi et al. 2008).

The multiple regression equation between soil respiration rate and rainfall and air temperature shows that rainfall have more influence than the mean air temperature on soil respiration rate while in stand II reverse is the case with mean air temperature showing a greater impact on soil respiration which may be due to site aspect factor. Chapman and Thurlow (1998) also reported that rise in mean annual temperature of 5°C could potentially increase CO₂ emission by a factor of 2 to 4. It is concluded that temperature and moisture are two most important factors which controls the rate of soil respiration. A strong seasonal response in the soil respiration rate, influenced by the prevailing climatic conditions, i.e., rainfall and temperature in the subtropical oak ecosystems in northeastern India exists

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