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Summer Fluxes of CO_2 from Soil, in the Coastal Margin of World's Largest Mangrove Patch of Sundarbans – First Report

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ABSTRACT

Soil CO_2 effluxes were investigated in the land-ocean boundary situated at the mangrove forest of Indian Sundarbans during the summer months of April and May' 2011. The soil CO_2 efflux ranged from 1.207 to 1.780 µ mol m^{-2} s^{-1} during the study period with a mean of 1.53 ± 0.17 µmol m^{-2} s^{-1}. Soil temperature at 2 cm and 10 cm depth was found to show the strongest correlation with soil CO_2 efflux. The efflux rate was controlled by the tides and consequently soil moisture. A negative correlation between soil moisture at 2 cm depth and soil CO_2 efflux was observed. The Q_{10} values (summer) ranged from 1.479 to 2.356 with increasing depth from 2 to 10 cm. On an average the mangrove soils were found to emit 242.51 mg CO_2 m^{-2} hr^{-1} during day time.

KEY WORDS: Below-canopy; chamber technique; mangrove soil; soil temperature; soil moisture; Sundarbans, India.

INTRODUCTION

CO_2 is one of the key greenhouse gases that contribute to Global warming [1]. Apart from anthropogenic activities, natural ecosystems also emit CO_2. Soil CO_2 efflux (SCE) is one the most important factors controlling the global carbon budget and is sensitive to increasing global temperature [2]. Through the carbon cycle, CO_2 is produced by both plant respiration and microbial respiration that occurs during decomposition of litter and soil organic matter [3]. The flux of microbial and plant respired CO_2 from the soil surface to the atmosphere, is the second largest terrestrial carbon flux. However, the dynamics of SCE are not well understood and the global flux remains poorly constrained [4]. Soil temperature and Soil moisture are two of the most important environmental parameters controlling variations in SCE [4] and their inter-relationship vary in different ecosystems [5]. Below canopy CO_2 flux are useful for explaining the diel variation in ecosystem process near the forest floor [6, 7].

Mangroves are an important ecosystem influencing global carbon budgets because of their high productivity and high carbon stocks in the soils [8]. In case of mangroves, apart from soil temperature and moisture, tidal amplitude and inundation period also explains the nature and magnitude of effluxes [9].
From the available literature, it is observed that a very few studies on soil CO_2 efflux in mangrove patches are reported till date [10, 11, 12, 13]. This is why the Global database of soil CO_2 efflux is still poorly constrained. Previously canopy respiration and atmosphere-biosphere studies were conducted [14, 15] but no prior initiatives were undertaken to study the in-situ soil respiration status in the Sundarban mangrove ecosystem, which happens to be the largest mangrove patch of the world.

The present study primarily aims to quantify the magnitude of SCE in coastal margin of a mangrove patch in Indian Sundarbans during the summer months and examine the relationship between flux and soil characteristics and other physical factors. The summer months of April and May are purposefully chosen to carry out the work because the soil temperatures reach maximum during this time of the year and soil CO_2 efflux is often found directly proportional to it [16]. Hence in order to estimate the maximum flux rates due to high soil temperature, this period was found appropriate.

MATERIALS AND METHODS

Study area

The mangrove forest of Indian Sundarbans lies between 21° 32′ and 22° 40′ N latitudes and between 88° 05′ and 89° E longitudes comprising an area of 9630 km^2 out of which 4264 km^2 is under the arena of reserve forest. East to West it stretches for about 140 km and from the southern shoreline end to northern limit it extends for about 50-70 km. The seasons in this unique bio-climatic zone at the land–ocean boundary of the Northern Bay of Bengal is demarcated into monsoon (June to September), post-monsoon (October-January) and pre-monsoon (February-May).

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The present study was conducted in the mangrove patches of Henry Island (21°34'27.11"N, 88°17'34.06"E) situated at the southernmost tip of the Sundarban mangrove forests. This geographical locale is primarily selected due to its vicinity from the Bay of Bengal. The effect of tides in this section of landmass is very pronounced, which makes the study of CO_2 fluxes with varying tidal amplitude successful. The tidal nature in this part of the world is semi-diurnal, with two high tides and two ebbs in 24 hours a day. Among the flora, *Avicenia officinalis*, *Aegiceras corniculatum*, *Agialites rotundifolia, Avicenia alba* and *Bruguiera gymnorrhiza* are found to be abundant in this patch.

Soil CO_2 efflux analysis

SCE was measured at hourly intervals in the months of April and May'2011, using a closed chamber of basal area 0.09 m^2 and 0.2 m height following the standard methods described by Keith and Wong [17]. The work was carried out once every week, covering eight days of the two months. As the entire experiment was conducted in manual presence, only day-time data could be logged. Due to safety reasons and obvious risks inside the forests, the night time study is deliberately opted out. For each measurement, the initial ambient concentration in the chamber is measured with LI-840A CO_2/H_2O Gas Analyzer (LI-COR, inc. USA) using a flow meter, passing air at the rate of 1 litre min^{-1} and the lid was closed for 10 minutes. The increased concentration was measured in the same way. The instrument was daily calibrated before and after the collection of data. The error in estimation was computed with the help of standard CO_2 and it varied between ± 0.004%.The SCE was calculated as per the formula [18]:

$$SCE = \frac{PV}{RTA}\left(\frac{dC}{dt}\right)................(1)$$

where SCE is the soil CO_2 efflux (μmol m^{-2} s^{-1}), P stands for air pressure, R is the universal gas constant (8.21 × 10^{-5} m^3 atm K^{-1} mol^{-1}), V and A is the volume (m^3) and surface area (m^2) of the chamber, T denotes absolute temperature (K) within the chamber and dC/dt is the rate of change in CO_2 concentration (μmol mol^{-1}) during the period dt (s). Atmospheric variables like air temperature, pressure and relative humidity were measured using a weather station (La Crosse Technology, WS-2350).

Three replicate sampling was carried out within 1 km^2 area at 3 equi-spaced inter-tidal positions lying 100 m apart from each other. All the data tabulated in the present study is the mean of three samplings. Soil temperature was measured at depths 2 cm, 5 cm and 10 cm using thermocouple probes (Multi, H9283). Soil moisture was monitored at the same depths using Leutron, PMS-714 moisture meter. 5 random soil core samples were collected from the top strata (0-30 cm) in both the months and all the physico-chemical parameters were analysed following standard methods of Page et al. [19]. The relationship between summer fluxes and soil temperature were estimated based on the exponential model of Lloyd and Taylor [20]: $SCE = ae^{bT}$ where 'a' and 'b' are the constants and T is the soil temperature at a particular depth. Consequently the Q_{10} (summer) values which denotes the factor to be multiplied to the efflux rate for a 10°C rise in temperature is evaluated as per the formula: $Q_{10} = e^{b\times10}$ [21].

Statistical analysis

The data analysis and graphical representations were done using the software EXCEL 2007. Pearson correlation co-efficient at 99 % level of confidence was calculated to examine the inter-relationship between efflux and soil temperature and moisture.

RESULTS AND DISCUSSION

The soil CO_2 efflux was monitored in 8^{th}, 15^{th}, 22^{nd} and 29^{th} April and 7^{th}, 14^{th}, 21^{st} and 28^{th} May'2011. The two consecutive dates were the 5^{th} and 12^{th} day of each lunar cycle. The tidal amplitude is tremendously influenced by the lunar cycle. Efflux monitoring could not be done during the spring tide sessions, as the entire study site one day before and after the new moon and full moon used to remain submerged under water. During low tide the water used to recede and forest floor used to become visible but even then it was found unfit for analysis. During this time, i.e. 6 days in a month, the diffusion process from soil pores to atmosphere is barred as the soil-atmosphere interface is blocked due to water logging. During the other days of the lunar cycle the soil remained exposed to atmosphere throughout 24 hours a day, leading to measurable efflux of CO_2. The data were logged in dates that lied in the mid of a lunar cycle when there was no effect of spring tide (Table 1). The tidal amplitude varied from 1.46±0.37 m (low tide) to 4.57±0.33 m (high tide) during the study period (data source: tides.mobilegeographics.com).

The atmospheric temperature below the canopy varied between 30.9 – 41.4°C during the study period. A fairly high relative humidity (65 ± 9 %) was observed below canopy throughout the day-time. The mean soil pH and electrical conductivity was 7.28 ± 0.12 and 7510 ± 57 μS cm^{-1} respectively. The mean sand, silt and clay content were in the order of 31.8, 33.7 and 34.5% respectively. An organic carbon content of 9.3 ± 1.1 mg/g was observed in the top soil (0-30 cm). An average N: P: K ratio of 5:1:14 was noted in the same layer. The soil temperature and moisture in the top soil was found to vary in the range 27.1 to 36.2 ^oC and 0.6 to 30.1% respectively. The average forest floor CO_2 concentration was in the order 387.13 ± 5.36 ppm and 2.5 m above the floor it was 374.56 ± 4.53 ppm during the entire study period. A mean SCE rate of 1.53 ± 0.17 µmol m^{-2} s^{-1} is observed with a maximum efflux of 1.780 µ mol m^{-2} $s^{-1}$and a minimum of 1.207µ mol m^{-2} s^{-1}. The diurnal variation of SCE during the day-time is plotted in Fig. 1.

Table 1: The date-wise soil CO_2 efflux (SCE) values (in µmol m^{-2} s^{-1}) obtained as a mean of three replicate sampling during the study period

Time (hours)	08.04.11 SCE	15.04.11 SCE	22.04.11 SCE	29.04.11 SCE	07.05.11 SCE	14.05.11 SCE	21.05.11 SCE	28.05.11 SCE
600	1.19	1.23	1.25	1.27	1.31	1.28	1.20	1.59
700	1.22	1.31	1.26	1.27	1.29	1.40	1.33	1.35
800	1.25	1.29	1.27	1.31	1.22	1.31	1.26	1.27
900	1.29	1.40	1.33	1.35	1.36	1.24	1.39	1.56
1000	1.32	1.34	1.35	1.39	1.40	1.42	1.52	1.52
1100	1.36	1.39	1.62	1.63	1.65	1.71	1.69	1.55
1200	1.52	1.52	1.53	1.36	1.39	1.62	1.63	1.65
1300	1.71	1.69	1.54	1.56	1.58	1.58	1.60	1.65
1400	1.66	1.26	1.68	1.70	1.72	1.73	1.76	1.77
1500	1.73	1.75	1.76	1.78	1.72	1.73	1.76	1.77
1600	1.53	1.53	1.59	1.62	1.64	1.65	1.71	1.69
1700	1.54	1.56	1.58	1.59	1.60	1.65	1.66	1.62

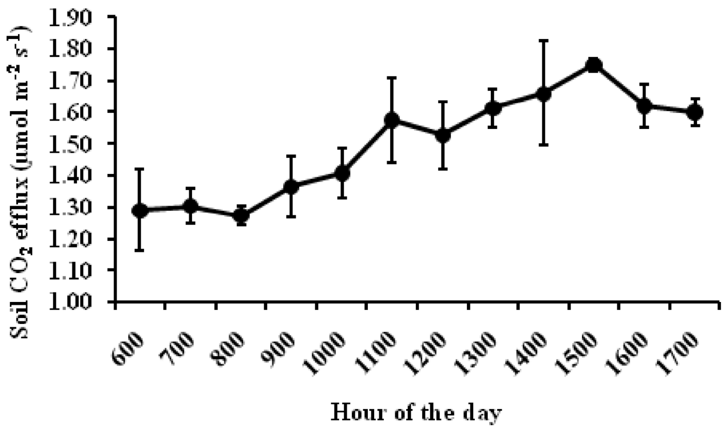

Fig. 1: The hourly variation of soil CO_2 efflux rate (error bars showing the standard deviation)

Diurnal variations of SCE were highly associated with variations of soil temperature at depths 2 cm, 5 cm and 10 cm. The strongest correlation however is observed with temperature at 2 cm depth (r= 0.821, p= 0.000) (Fig. 2) and 10 cm (r= 0.821, p= 0.001) followed by 5cm (r= 0.811, p= 0.000) [n = 288]. The probable reason may be the root system and microbial activity in the top soil layer is most active. In general lowest SCE values were recorded during highest high tide (high moisture content in soil) and vice-versa. This fact is supported by a negative correlation noted between SCE and soil moisture at 2 cm depth (r= -0.691, p= 0.001) [n=288]. Soil moisture at depths below was more or less constant and did not show any variation with tidal effects. An increase in Q_{10} values were detected with increasing depth [ST 2 cm- 1.479 (r^2= 0.6748), ST 5 cm- 1.680 (r^2= 0.658) and ST 10 cm- 2.356 (r^2= 0.6746)]. Tang et al. [16] observed during hot and humid summers, mean soil respiration rates of 616.1±22.8, 521.2±16.0 and 370.0±18.4 mg CO_2 m^{-2} h^{-1} in broadleaf forests, mixed forests and pine forests respectively. The mean efflux rate observed here is 242.3±26.9 mg CO_2 m^{-2} h^{-1}, which is well below compared to the above mentioned. The maximum SCE (during the peak of summer) found here is 6.408 mmol m^{-2} h^{-1} which is found higher than the maximum of 1.67 mmol m^{-2} h^{-1} observed in Jiulongjiang mangrove estuary, China [12] but lesser in comparison to 20.56 mmol m^{-2} h^{-1} in the Shenzhen and Hongkong mangroves, South China [13] and 16.48 mmol m^{-2} h^{-1} in Nakaumi coastal lagoon, Japan [10], but it is closely comparable to that of 6.84 mmol m^{-2} h^{-1} in the tidal flat of Yangtze estuary, China [11]. The mean SCE found here during the summer (5.51 mmol m^{-2} h^{-1}) was eventually found higher than the mean value of 2.87 mmol m^{-2} h^{-1} measured over 75 mangrove swamps [22].

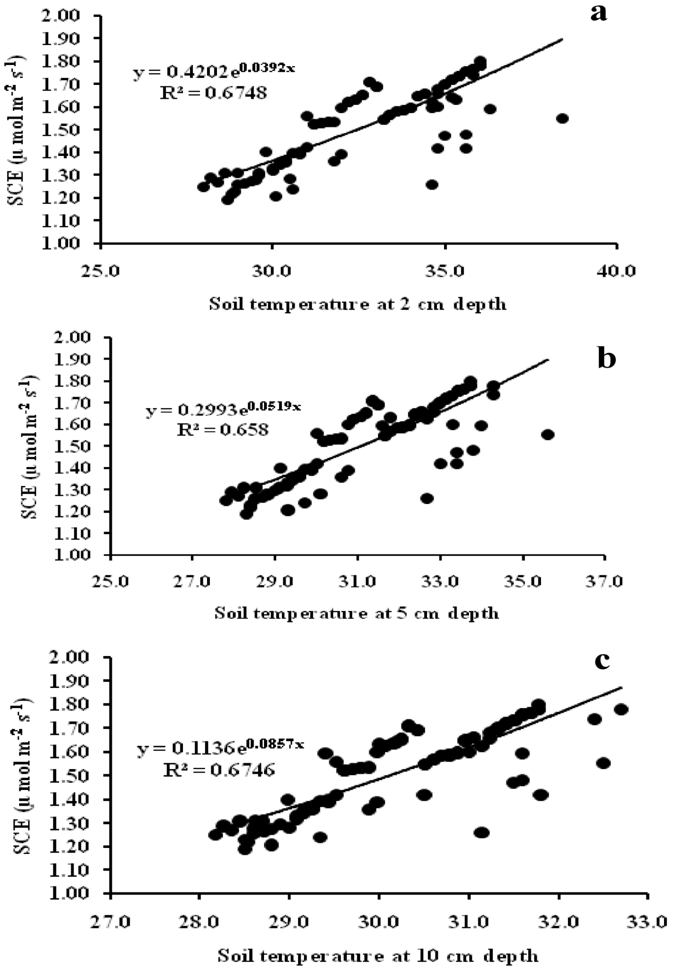

Fig. 2: The exponential relationship between soil CO_2 efflux and soil temperature at (a) 2 cm depth, (b) 5 cm depth and (c) 10 cm depth. (Data points are the mean values of 3 replicate sampling)

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