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Full Length Research Paper

Factors influencing soil CO_2 efflux in a northeastern Indian oak forest and plantation

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Temporal changes in soil CO_2 efflux rates were measured in a subtropical natural mixed oak forest and managed oak plantation in the northeastern Himalayan region. Soil CO_2 efflux rates in two ecosystems were correlated with key soil biotic (e.g. fungal, bacterial and actinomycetes populations) and abiotic (e.g. soil moisture, temperature, pH and organic carbon concentration) variables. Rate of CO_2 efflux (mg CO_2 m^{-2} h^{-1}) at forest and plantation sites varied between 102 - 320 and 99 - 543, respectively. The concentration of soil organic carbon was higher at plantation than natural forest. Bacteria and actinomycetes were dominant species at plantation, whereas, the fungi were dominant at forest. CO_2 efflux at both sites was significantly positively correlated with the populations of these three microbial groups. Among abiotic variables, soil temperature and pH played significant positive role on the rates of soil CO_2 efflux in forest while variables like soil moisture and organic carbon were least accountable. In contrast, at plantation soil CO_2 efflux was significantly positively correlated with soil moisture, temperature and pH. In the present study, CO_2 efflux was not influenced by the organic C concentration, however, it was affected by the other abiotic and biotic variables. CO_2 efflux rates at plantation was regulated by the presence of bacteria and actinomycetes, whereas, it was controlled by the population of fungi in the natural forest. Management practices operated in plantation appears to affect the group of microbial populations that further affect the soil CO_2 efflux rates.

Key words: Soil CO_2 efflux, biotic and abiotic variables, natural oak forest, managed oak plantation.

INTRODUCTION

The emission of soil CO_2 as a result of respiration from terrestrial biosphere represents the second largest global flux of CO_2 to the atmosphere after the ocean (Schlesinger and Andrew, 2000). Forests play a major role in the global carbon (C) cycle by sequestering about 62 - 78% of the global terrestrial C pool, of which about 70% of C is stored in the soil (Dixon et al., 1994; Schimel, 1995) . Forest soils accumulate significantly higher C than other land uses such as savanna and agro-ecosystems and thus a small alteration in soil CO_2 flux may lead to a considerable change in atmospheric CO_2 concentration (Bouwmann and Germon, 1998; Raich and Tufekcioglu, 2000; Hagedorn et al., 2001) . Tropical forest constitute about half of the world's forest area and play an important role in the global C cycle by storing 46% of the world's living terrestrial C pool and 11% of the world's soil C pool (Brown and Lugo, 1982).Thus, tropical forests represent the major resource for mitigating climate change because of their ability to sequester and store large quantities of carbon (Canadell and Raupach, 2008). In Indian tropical regions, the occurrence of extensive landscape transformations from natural forests to degraded landforms is accompanied by changes in soil structure and quality (Tripathi et al., 2008) due to opening up of crown cover, decreased soil organic matter content and reduced efficiency of nutrient cycling (Singh, 1989; Tripathi and Singh, 1994).

Soil CO_2 efflux is mainly regulated by the oxidation of soil organic matter during litter decomposition by heterotrophic microorganisms and the respiration by plant roots. Thus, the population dynamics of soil microorganisms (e.g. bacteria and fungi) and the soil abiotic factors (that is, temperature, moisture, organic matter content) are the major factor playing important role in the emission of CO_2 by soil (Schlentner and Van Cleve,

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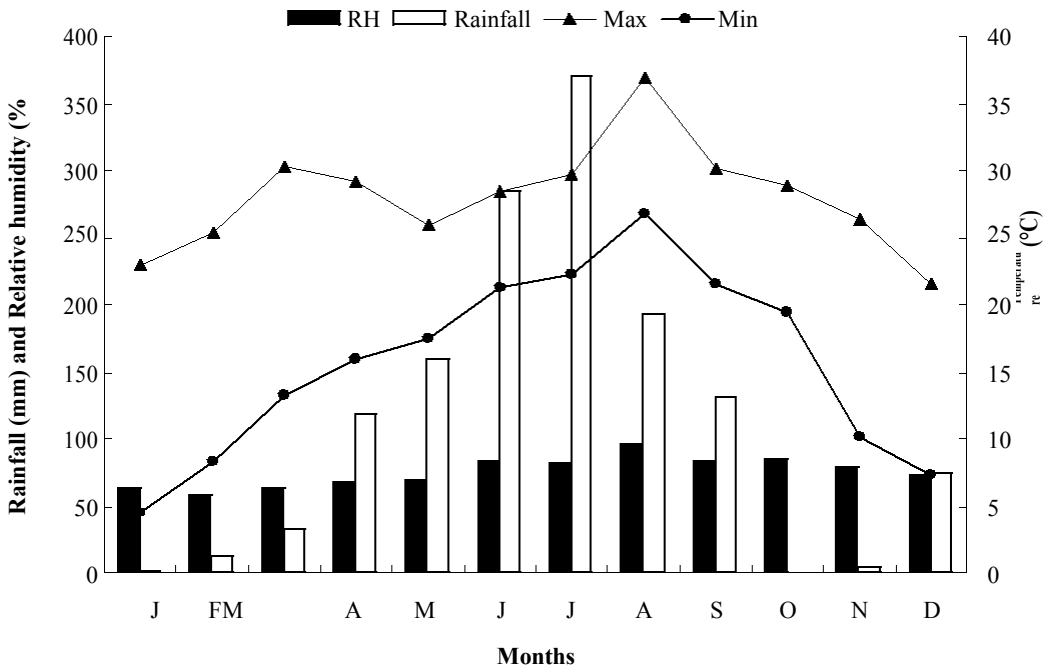

Figure 1. Climatic data during study period with monthly rainfall (mm), relative humidity (%) and mean minimum and maximum temperature (°C).

1985; Bouma and Bryla, 2000; Muhr et al., 2008). In addition, abiotic factors affect the gaseous diffusion and metabolic activity of soil microorganism and therefore, control the dynamics of soil microorganisms and their metabolic activities within sites (Raich and Potter, 1995; Davidson et al., 1998).

Forest management practice like thinning is reported to influence soil CO_2 efflux as a result of changes in micro-environmental conditions, mainly soil microclimate and root dynamics (Tian et al., 2009) . Similarly, management practices adopted in plantations can influence the labile fraction of the soil organic carbon stock through increased metabolic activity of microbial population (Ellert and Gregorich, 1995) and affect quality, fertility and C storage capacity of the soil (Henderson, 1995; Lal, 2005). Intensity of effects may vary among different forest types of the world depending on the management strategies applied. The management practices in oak plantation have been reported to affect the decomposition process and nutrient release patterns of leaf litter as compared to natural oak forest (Pandey et al., 2007). However, there is limited research to document the effects of management practices like amendment of organic manures and NPK fertilizers on the changes in physico-chemical and biological properties like microbial populations and CO_2 efflux rates of plantation soils (Tiwari, 1996; Hagedorn, 2001). The present study aims to investigate the temporal changes in soil CO_2 efflux rates and the impact of key soil biotic and abiotic factors on monthly variations in CO2 efflux rate in natural oak forest and managed oak plantation in north-eastern India.

MATERIALS AND METHODS

Site description and climate

The present study was conducted in a natural mixed oak forest and managed oak plantation (24°51′ - 24°56′ N Lat and 93°52′ - 93°58′ E Long; at an elevation of 840 and 790 m a.m.s.l., respectively) in the state of Manipur India. Geographically about 90% of the total area of Manipur is covered by hill ranges which are the offshoots of eastern Himalayas with about 1813 km^2 central valley area (Sehgal et al., 1993). The forest was located to the gentle slope of a hillock at a distance of 15 km on the north of Imphal city and plantation was situated in valley area about 8 km away from the city in the same direction. Both sites are 7 km apart from each other and have similar climatic conditions like rainfall and temperature. The climate of the area is monsoonic with warm moist summers and cool dry winters. The mean monthly daily averages of minimum and maximum temperature during the study period (January-December, 2003) ranged between 13.7 and 31.8°C in the months of January and August, respectively (Figure 1). Likewise, the mean monthly daily averages of relative humidity ranged from 57.7 - 95.6%. The total annual rainfall was 1384 mm of which about 73% occurred in 4 months of the year from May to August.

The forest vegetation was dominated by *Quercus serrata* Thunberg along with other woody associates like *Acacia australiensis, Engelhardtia spicata, Flacourtia cataphracta, Holigarna longifolia, Schima wallichii, Toona ciliata* and *Wendlandia grandis*. The ground flora was better developed at forest than the plantation and formed by species of herbs and seedlings of trees. At plantation, *Q. serrata* trees were planted in a large area (ca. 40, 000 ha land in Manipur state only) at a regular distance of 1.25 –

Table 1. Major vegetation and soil characteristics of natural oak forest and plantation in Manipur, northeast India.

Parameters	Forest	Plantation
Vegetation		
Tree age (years)	75- 80	30 - 32
Range of oak tree height (m)	11- 14	3 - 4
Mean tree girth (cm)	57.3 ± 8	33±1
Crown cover (%)	33	63
Density (tree ha^{-1})	1567	7040
Total tree basal cover (m^2 ha^{-1})	41	61
Soil		
Organic carbon (g kg^{-1})	16- 26	25 - 32
Organic carbon (kg ha^{-1})	27300	36400
Total nitrogen (g kg^{-1})	1.6- 2.9	2.4 - 6.9
Total nitrogen (kg ha^{-1})	3250	6300
Available phosphorus (g kg^{-1})	0.05- 0.09	0.07 - 0.09
Available phosphorus (kg ha^{-1})	91	112
Exchangeable potassium (g kg^{-1})	1.6- 2.4	2.0 - 3.2
Exchangeable potassium (kg ha^{-1})	2600	3640

Soil organic carbon and nutrient concentrations (g kg^{-1}) are reported as the range of annual variations in upper 10 cm soil. Accumulation of organic carbon and nutrients (kg ha^{-1}) are reported as product of mean concentrations and bulk density.

1.5 m and are managed by Regional Tasar Research Station, Imphal.

The leaves of oak trees at plantation served as the primary feed for the larvae of a temperate silk worm *Antheraea proylei* Jolly for production of quality yarn of Tasar silk (Jolly et al., 1974), and so this species has the sole economic value in this region. The common management practices consisted of periodical weeding and pruning of shoots (during January- February) and incorporation of chemical fertilizers, organic manure and bio-fertilizers into the surface soil once a year (during May–June) around 1 m^2 area of each tree trunk base to enhance the soil fertility for improving plant health and leaf quality for silk moth (Singh et al., 2001). Exogenous annual soil amendment in plantation was made as: Chemical fertilizer (equivalent to nitrogen at 150 kg ha^{-1}, phosphorus at 50 kg ha^{-1}, potassium at 38 kg ha^{-1}) and farmyard manure (FYM, equivalent to carbon at 2450 kg ha^{-1}, nitrogen at 126 kg ha^{-1}, phosphorus at 17 kg ha^{-1}, potassium at 25 kg ha^{-1}). In addition, phosphate solubilizing microorganisms (PSM) and nitrogen fixing microorganisms (NFM) were also added at the rate of 20 kg^{-1} yr^{-1} to sustain productivity (Srivastava and Singh, 1999).

Ages of oak trees were 70 - 80 years at forest and 30 - 32 years at plantation. Two sites have similar climatic conditions with respect to major climatic and edaphic factors except microclimatic conditions of the sites due to management practices. According to USDA classification, the soil is Ultisol developed from shale and sandstones on gentle sloping narrow valleys to steep side slopes of hills and is heterogeneous in nature (Sehgal et al., 1993). The soils at both sites have developed from the same parent material having different soil texture. Since two sites are from the same parent material but the changes in soil texture and colour are due to variation in geomorphic landscapes, for example, forest is on piedmont slope at Maharabi and the plantation is in the vicinity of Imphal valley floor which is believed to be a part of famous Loktak lake. The fine textured soil at plantation is developed during centuries because of the clay and silt deposits from the nearby forest and water lodging condition in the past. The soil profile in forest was shallow (that is, only 10 cm deep at certain places) whereas, it was deep (>1 m) at plantation site. Soil pH at both the sites is slightly acidic (5.6 - 6.5) in nature. Soil organic carbon C, total N, available P and exchangeable K were higher in plantation than forest (Table 1). The oak trees (*Q. serrata*) dominated the forest along with other woody associates like *S. wallichii* , *T. ciliata*, *A. australiensis* and *W. grandis*. Ground flora was better developed at forest than plantation and formed by the species of herbaceous and woody species seedlings (Table 1). Further details of soil, litter and vegetation composition at two sites and management practices operated in plantation were reported by Pandey et al. (2007).

Experimental design and measurement of soil CO_2 efflux

At each site 3 permanent plots each measuring 10 × 15 m were marked and within each permanent plot two randomly located points were demarcated. A total of six CO_2 measurement points were established at each site. From each point freshly fallen litter was removed along with the herbaceous component two-three weeks prior to the beginning of the study and open ended galvanized iron cylinder (20 cm height ×14 cm diameter) were pressed ca. 5 cm into the soil every time at each point. A beaker (100 ml) containing 20 ml 0.1 N KOH solution was placed on a tripod on the ground surface after clipping herbaceous shoots, if any, before the start of the measurement at each month. The bottom ends of cylinder were pressed into the soil and the upper ends were tightly sealed with a metal lid along with a polythene

sheet. After 24 h, the amount of CO_2 absorbed by the residual alkali was subsequently measured by standardized titration against 0.1 N HCl using phenolphthalein as an indicator. The CO_2 outputs inside the boxes were calculated by following formula as described by Witkamp (1966a and b, 1969): $m(CO_2) = V \times N \times 22$; where $m(CO_2)$ is the mass of captured CO_2 in mg, V= volume of HCl used in titration against saturated KOH solution (ml) and N= Normality of HCl. The results were expressed in terms of mg CO_2 m^{-2} h^{-1}. Soil CO_2 fluxes have been and are still being measured with chambers using chemical traps for absorbing emitted CO_2 for more than eight decades and remain the most commonly used approach. This technique permit measurement of very small efflux of CO_2 from the soil surface, are relatively inexpensive to build and use, and can be adapted to a wide range of field conditions and experimental objectives (Rochette and Hutchinsson, 2005). So, this is very useful to record multiple time integrated measurements at remote locations. The results obtained by this method is often described as inaccurate, either underestimating (Norman et al., 1992; Rochette et al., 1992) or sometimes overestimating (Bekku et al., 1997), and thus, the values of CO_2 efflux obtained by this method are considered by many as unreliable but reported as best estimates for the relative difference between sources (Minderman and Vulto, 1973; Singh and Gupta, 1977; Norman et al., 1997). Gupta and Singh (1981) compared CO_2 efflux rates from permanently-fixed and movable cylinders in Indian tropical grassland and concluded that the soil respiration was not affected by the time of enclosure.

Collection and measurement of soil physico-chemical properties

The surface soil (0 - 10 cm depth) beside one galvanized iron cylinder from each plot was collected in polyethylene bags at monthly interval from both sites and brought to the laboratory for further analysis. A total of 36 collections from each stand were made from January, 2003 to December 2003.

Soil temperature from 0 - 10 cm depth was recorded using soil Elite thermometer having 32 cm length, 0.7 cm diameter with 2.5 cm long mercury bulb made by Elite Scientific Corporation, Ambala Cantt, India. Beside each iron cylinder hourly temperature measurements was recorded between 8 AM to 4 PM on the date of recording of CO_2 efflux and the data were presented as mean of 0 - 10 cm soil depth. Field moist soil was weighed fresh and oven dried to constant weight and moisture content was calculated. Soil pH was determined by the method of Anderson and Ingram (1993). The soil texture was determined by Bouyoucos hydrometer method (Allen et al., 1974). The soil organic carbon was estimated by rapid titration method (Walkley and Black, 1934).

Estimation of microbial population

Quantitative estimation of soil fungi, bacteria and actinomycetes were made according to the serial dilution (suspension) plating method as described by Parkinson et al. (1971). 10 g freshly collected ground soil of each study site was suspended separately in 250-ml Erlenmeyer flasks containing 100 ml distilled water and thoroughly shaken for 15 min on a horizontal mechanical shaker. The suspension was further diluted to first to 10^{-4} and then to 10^{-5} using sterile distilled water. 1 ml aliquot of 10^{-4} dilution for fungi and 10^{-5} dilution for bacteria and actinomycetes was inoculated separately into each of five Petri dishes. 20 ml molten and cooled (40°C) Martin's agar (Martin, 1950), Thornton's agar (Thornton, 1922) and Jensen's agar (Jensen, 1930) media was poured separately into each Petri dish for selective isolation of fungi, bacteria and actinomycetes, respectively. The dishes were incubated at 25 ± 1°C for fungi and 30 ± 1°C for bacteria and actinomycetes. The microbial colonies were counted after 2, 5 and 7 days of incubation for bacteria, actinomycetes and fungi, respectively. The average number of colony forming units (CFUs) was calculated as counts g^{-1} dry soil.

Statistical analysis

Correlation and linear regression analyses were used to examine the relationships between soil CO_2 efflux and soil biotic and abiotic variables. Stepwise multiple regression analysis was also performed to understand the combined effect of biotic and abiotic variables on the rate of soil CO_2 efflux by statistical software SPSS.

RESULTS

Physico-chemical properties of soil

The soil of the forest stand was 10 - 40 cm deep, reddish in colour and sandy loam (sand 51%, silt 32%, clay 17%) in texture. Plantation soil was about 1 m deep, light grey in colour and clayey loam in texture (sand 36%, silt 29%, clay 34%). Soil temperature varied from 15 - 24°C at both sites during the study period (Figure 2) . Gravimetric soil water content ranged from 16.2 - 38.1% and 14.3 - 38.9% in forest and plantation sites, respectively. Soils at both sites were slightly acidic in reaction and pH ranged from 5.58 - 6.63 (Figure 2).

Changes in soil CO_2 efflux

Soil CO_2 efflux rate varied considerably between the two sites (Figure 3). During the study period, soil CO_2 efflux varied from 102 - 320 and 99 - 543 mg CO_2 m^{-2} h^{-1} at forest and plantation sites, respectively. At forest site, maximum soil CO_2 efflux was recorded in June and minimum in December. At plantation, CO_2 efflux was lowest in January and increased consistently till June and then decreased in the following month with the main peak in September.

Changes in microbial population

The monthly soil microbial counts (CFU g^{-1} dry soil) comprising fungal, bacterial and actinomycetes populations varied considerably between forest and plantation sites. Bacteria and actinomycetes populations were more abundant in plantation soil whereas, in forest soil greater population of fungi was recorded throughout the study period. The patterns of monthly variation in microbial counts were not significantly different in both sites (Figure 4), but marked seasonal variations in the microbial population were recorded. At both sites, microbial population increased consistently from January to June when the highest counts for all three microbial groups were recorded. During this period the population (CFU g^{-1} dry soil) of fungi, bacteria and actinomycetes at

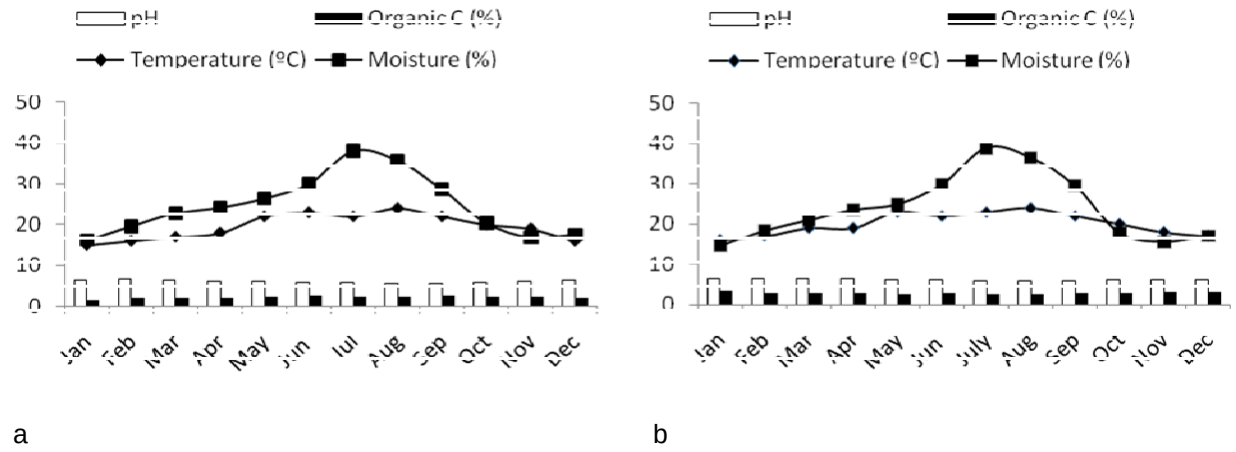

Figure 2a and b. Monthly variation in physico-chemical properties of soil (0 - 10 cm depth) at forest and plantation sites.

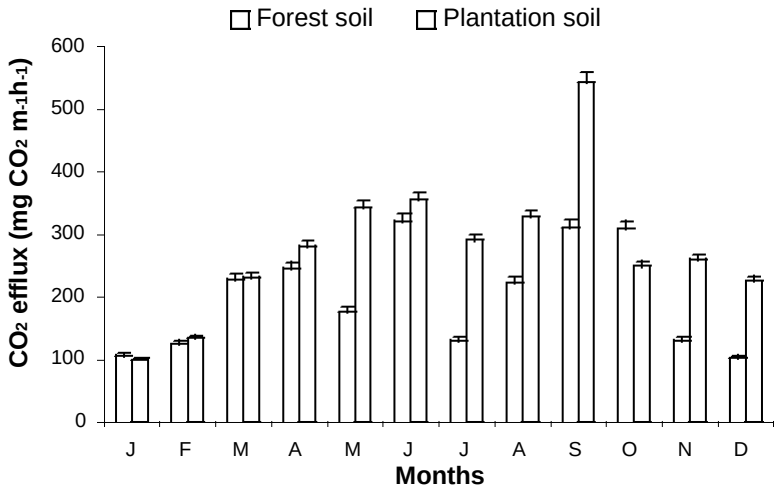

Figure 3. Monthly variations in soil CO_2 efflux rates of forest and plantation sites.

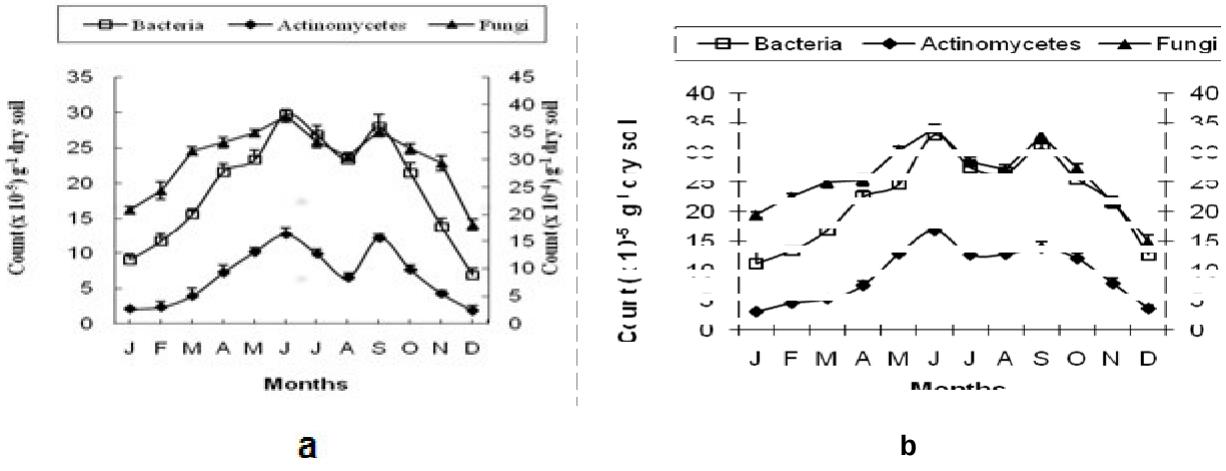

Figure 4. Monthly changes in microbial population in surface soil of forest (a) and plantation (b) sites. Values of bacteria and actinomycetes are plotted on the left y-axis and fungi on right y axis.

Table 2. Different parameters (values) of correlation coefficient between soil respiration rate that is, CO_2 efflux with biotic and abiotic variables at forest and plantation sites.

Variables	Forest site				Plantation site			
	Slope	Intercept	r	p <	Slope	Intercept	r	p <
Biotic variables								
Fungi ($\times 10^{-4}$ g^{-1} dw)	10.311	- 109.08	0.740	0.01	15.241	- 113.57	0.743	0.01
Bacteria ($\times 10^{-5}$ g^{-1} dw)	7.8407	49.391	0.720	0.01	13.016	- 10.109	0.825	0.01
Actinomycetes ($\times 10^{-5}$ g^{-1} dw)	14.954	100.39	0.695	0.05	18.879	102.1	0.766	0.01
Abiotic variables								
Soil moisture (%)	3.5309	112.6	0.316	ns*	8.1508	83.865	0.594	0.05
Soil temperature (ºC)	15.556	- 101.7	0.596	0.05	32.196	- 360.4	0.733	0.01
Soil pH	-148.81	1119.6	0.618	0.05	-416.2	2859.3	0.740	0.01
Soil organic matter (%)	166.95	-170.7	0.567	ns*	-214.27	872.38	0.399	ns*

ns* = not significant; r is the correlation coefficient and p is the probability.

forest site were 37.8×10^{-4}, 29.7×10^{-5} and 12.6×10^{-5}, respectively. Corresponding population values for these groups were: 34.0×10^{-4}, 32.9×10^{-5} and 16.7×10^{-5} at plantation (Figure 4). Thereafter a slight decline was recorded in the microbial counts during July and August at both sites. Another peak in microbial population was observed during September after which the counts of three microbial groups gradually declined till the last sampling (in December). The least microbial counts from both sites were recorded during winter season.

Relationship between soil respiration rate and biotic and abiotic variables

Significant positive correlations were observed between the soil CO_2 efflux rate and fungal ($r = 0.74$, $p<0.01$), bacterial ($r = 0.72$-0.82, $p < 0.01$) and actinomycetes ($r = 0.69$-0.76, $p < 0.05$) populations in forest and plantation sites (Table 2). At forest, soil CO_2 efflux rates were significantly positively correlated with soil pH ($r = 0.61$-0.73, $p < 0.05$) and soil temperature ($r = 0.57$ - 0.73, $p < 0.05$). Whereas, soil CO_2 efflux at this site was not significantly correlated with other abiotic variables like soil moisture and soil organic carbon (Figure 5). At plantation site, the rate of soil CO_2 efflux was significantly positively correlated with soil moisture ($r = 0.59$, $p < 0.05$), soil temperature ($r = 0.73$, $p < 0.01$) and soil pH ($r = 0.73$, $p < 0.01$) (Figure 6). Soil CO_2 efflux rates at these sites was not significantly correlated with soil organic carbon (Table 2).

DISCUSSION

The results of the present study is comparing the CO_2 efflux from the two sites having varying soil profile (shallow soil at forest and deep at plantation) where the surface soil play more important role in CO_2 efflux. In Indian tropical region upper soil depth has been found to represent the maximum root concentration and soil biological activity (Tripathi and Singh, 1992; Tripathi et al., 1999), so the result of the present study would be widely comparable to other studies in different forests. In the present study, minimum rate of CO_2 efflux from both sites was recorded in winter months as a result of decreased microbial populations (that is, reflected from lowest fungal, bacterial and actinomycetes populations) and possibly activity during this period. As the warmer months approached with frequent precipitation, the microorganisms inhabiting the soil became more active causing an enhanced CO_2 efflux rates from both the sites. Significant positive correlation of soil CO_2 with soil moisture and temperature has been reported by several investigators on different forest ecosystems (Rajvanshi and Gupta, 1986; Lomoander et al., 1998; Sundaravalli et al., 2001; Laishram et al., 2002). However, in the present study linear regression in case of temperature appears to be a non realistic tool to asses soil CO_2 efflux and thus, non linear curve may provide better reflection of CO_2 efflux from the soil (Figures 5 and 6).

Management practices operated in plantation have led to changes in soil and vegetation characteristics that result in altering microclimatic condition like soil moisture and temperature of these sites. Higher soil moisture and humidity in plantation could account for the high CO_2 efflux rate. Recently, Tian et al., (2009) reported strong effects of soil temperature and soil water content on soil CO_2 efflux in Chinese fir plantations. The reports from different ecosystems on the pattern of soil CO_2 efflux rate suggest that it is mainly influenced by the microclimatic

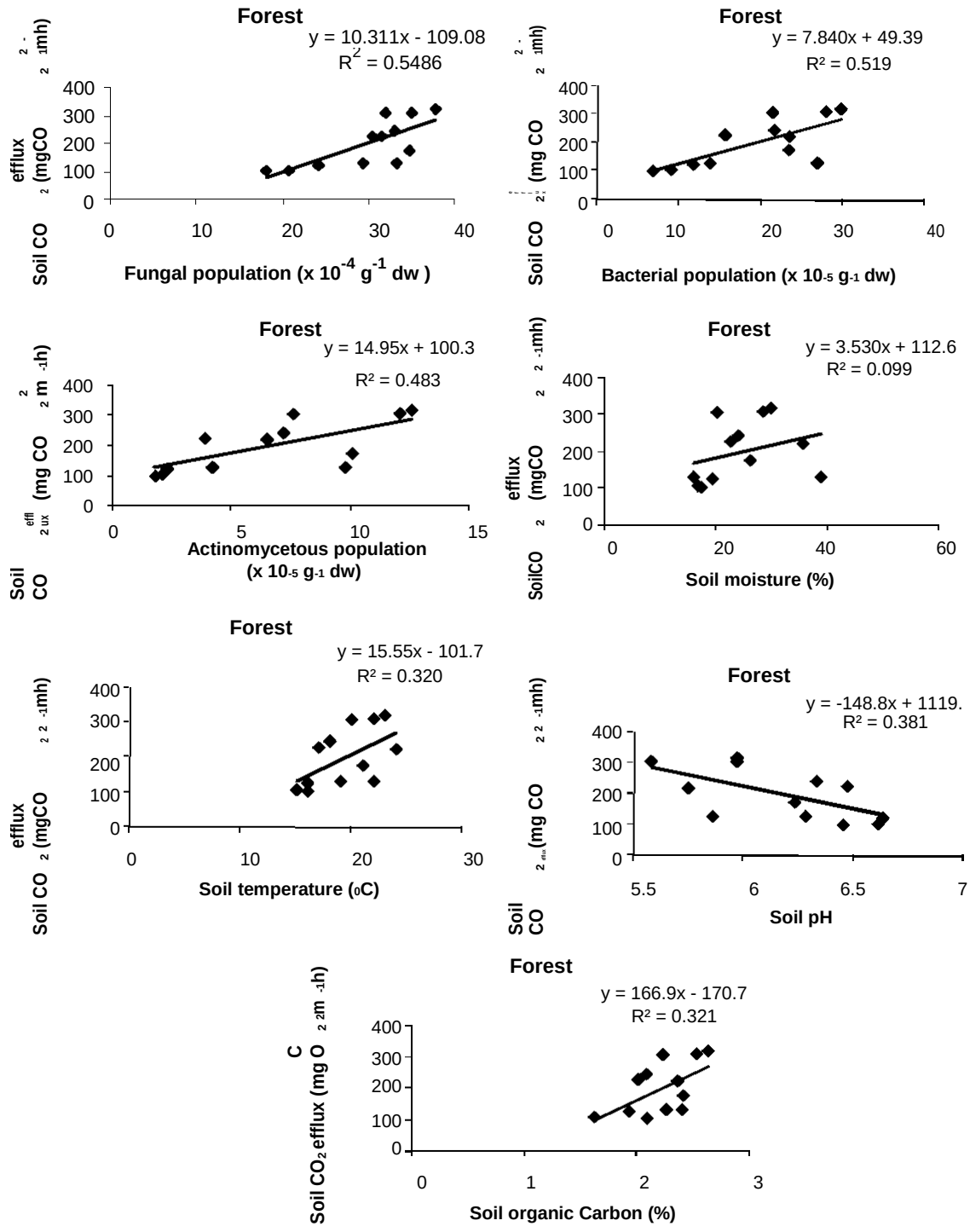

Figure 5. Soil CO_2 efflux (mg CO_2 m^{-2} h^{-1}) as function of biotic and abiotic soil variables at forest site.

variables which are affected by vegetation cover and soil management practices (Piao et al., 2000) . In plantation, reduced soil CO_2 efflux in July-August in our case was mainly because of water logging condition (as per our visual observation during the field) due to heavy rainfall that possibly created an anaerobic condition in the soil which inhibits microbial respiration (Tiwari et al., 1987) and to certain extend root respiration. However, decreased soil CO_2 efflux rate in forest was mainly because of increased runoff loss due to heavy rainfall during this period that may carry considerable amount of microbial propagules and may lead to decrease microbial

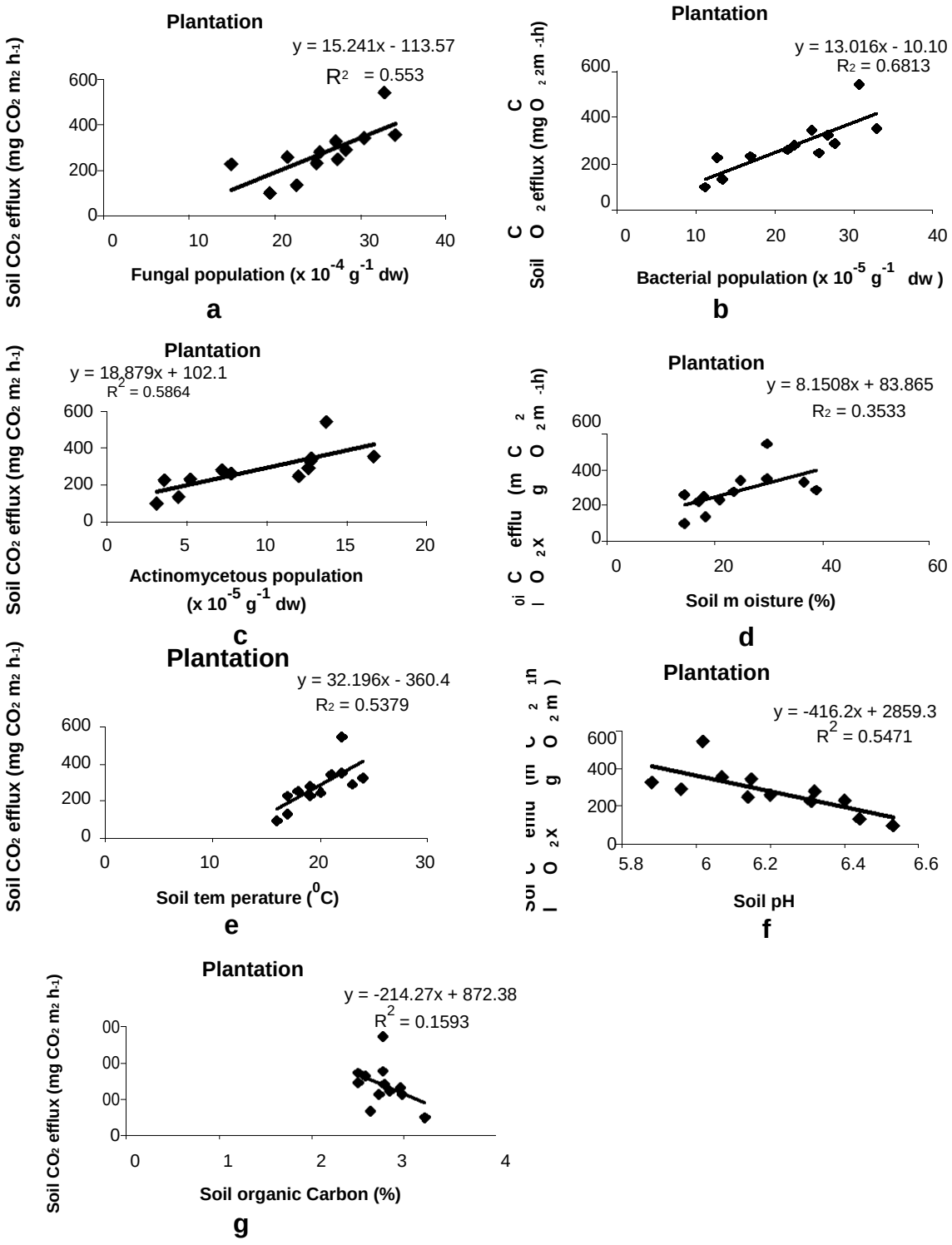

Figure 6. Soil CO_2 efflux (mg CO_2 m^{-2} h^{-1}) as function of biotic and abiotic soil variables at forest site at plantation.

count (as evident from Figure 4) and consequently microbial respiration during this period.

Higher CO_2 efflux rate at plantation compared to forest could also be due to the organic and inorganic amendments which might have supported more microbial growth and utilization of the available substrates by altering the respiratory quotient of microbes (Anon et al., 2001). Addition of inorganic fertilizer especially nitrogen

appears to have priming effect on increasing CO_2 efflux from the soil in the plantation site as evident from highest peak in the September (Figure 3) . This finding has important role in understanding the impact of nitrogen loading in these ecosystems and their response to CO_2 efflux at regional level that may significantly contribute to one of the important global change phenomena. Nitrogen addition in soil has been reported to increase the concentration of C in upper 10 cm soil of acidic loam (Hagedorn et al., 2001). The rate of CO_2 efflux recorded in the present study was broadly comparable to the range (368 - 634 mg CO_2 m^{-2} h^{-1}) reported by Laishram et al. (2002) from a mixed oak forest ecosystem at Shiroy hills in North-Eastern India.

We found significant positive correlations between CO_2 efflux rates and the three microbial groups at both sites which are in conformity with role of microbial population in soil CO_2 efflux. A significant positive correlation between soil respiration rate and populations of fungi, bacteria and actinomycetes has also been reported in Indian tropical and subtropical forests (Rai and Srivastava, 1981; Tiwari, 1996). The soil microbial population has been reported to be affected by the characteristic vegetation differences (McLean and Hunta, 2002) directly through the quality of litter and root exudates as the resource for microbes and indirectly through the changes in soil chemical and physical properties (Grayston et al., 1998).

The monthly variation in microbial population has been found to be mainly determined by soil physical factors especially the moisture and temperature of soil as well as the microbial activities in the proximal litter layer (Santo et al., 1978; Rai and Srivastava, 1981). The peaks in microbial counts during June and September can be attributed to favourable soil moisture and temperature which are supporting microbial activities and proliferation. Rahno et al. (1978) found that maximum counts of soil microbes occur usually at 25 - 30% soil moisture and after that either the microbial count are decreasing or showing no change. After September, higher soil moisture stress and lower soil temperature might have negatively affected the population of microbes and thus, lower microbial counts were recorded during the terminal winter months. In the present study, the dominance of bacteria and actinomycetes in slightly acidic soil suggests that pH is not a critical factor for the growth of these microorganisms in nature where other factors are also operating simultaneously. Williams et al. (1971) suggested that some groups of bacteria and actinomycetes are more widespread in acidic soils and hence, pH of the soil is not a major factor contributing to microfloral changes.

Conclusions and future outlook

In the present study, soil CO_2 efflux appears to be mainly regulated by the abiotic and biotic soil variables. Because biotic variables like microbial populations are significantly affected by altering patterns of temperature and precipitation. So, the study has strong implications on one of the important global change phenomena of increasing atmospheric CO_2 concentration due to changes in forest management practices. The rates of CO_2 efflux is mainly regulated by the presence of bacteria and actinomycetes populations at plantation, whereas, the same was controlled by fungal population in the natural forest. The role of soil organic C content on the efflux of CO_2 was not clear. Further studies on soil CO_2 efflux with varying amount of soil organic C would enhance our understanding on the role of soil organic C on CO_2 efflux from soil in this region. The addition of organic and inorganic fertilizer, especially N, appears to strongly enhance the soil CO_2 efflux rates in September in plantation site. So, this study has strong implication on predicted future environmental N loading on CO_2 efflux from the soil in this region that will ultimately contribute to the global C balance and managing one of the major environmental problems of the 21st century.

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