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Drivers of soil respiration dynamics of Graminaceous vegetations (*Bambusa tulda*) in lower Indian Himalaya

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Abstract

Soil respiration (*Rs*) and soil carbon stock (SOC) in vegetations measures the carbon sequestration and emission thereby provide precise estimate for greenhouse gas (GHGs) emission. The modeling of *Rs* with drivers of change leads to predict the future emissions from the vegetation along with their management and conservation. Therefore, a study was undertaken to evaluate and compare the *Rs* and SOC in planted *Bambusa tulda* and Grassland in the lower Indian Himalayas. *Rs*, SOC and other parameters were measured for two years by collecting monthly soil samples and floor litter to estimate soil characteristics besides various micro and atmospheric climatic parameters were also measured. The data were analyzed to compare seasonal soil characteristics for each vegetation and relationship was also established between *Rs* and soil characteristics and climatic parameters through stepwise linear regression. The available nitrogen and potassium significantly varied with the vegetation. *Rs* in Grassland were positively influenced by vapour pressure, however in *B. tulda* positively influenced by soil moisture and minimum air temperature. The C/P and N/P ratio was significantly different in years and C/K ratio was significantly different with vegetation. The *Rs* and SOC stock under *Bambusa tulda* and Grassland were 60.23 t ha^{-1} and 33.23 t ha^{-1}; and 109.94 t ha^{-1} and 79.22 t ha^{-1}, respectively. The analysis observed that *Bambusa tulda* has high sequestration and respiration rate in planted forest than grass, and moisture controls the *Rs*.

Keywords Soil CO_2 emission; SOC stock; Stoichiometric; Relative humidity; Litter; Vapor pressure

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1. Introduction

The understanding of soil CO_2 emission from bamboo forest and bamboo plantation is crucial for estimating the impact of carbon cycle on soils under bamboo. It helps in the maintaining carbon cycling on global and regional scales. Globally, it includes exchanges of CO_2 among the land biosphere, oceans, the atmosphere, and the earth's crust. Soil CO_2 emission is the process from which soil releases CO_2 to atmosphere. It is the important part for carbon cycling in terrestrial ecosystem. Soil emission were affected by various factors interactively. It is not sensitive to temperature changes under lower soil moisture (< 75%), but it is more responsive at higher soil moisture conditions (100- 250%). Similarly, soil respiration is not sensitive to moisture under minimum temperatures (< 5 ^{o}C) but more responsive at higher temperatures (10-20 ^{o}C) (Carlyle and Than 2012).

Bamboo forest is an important forest type and has expanded very rapidly in recent decades (Jia et al. 2009). About more than 10% of the carbon stock were stored in bamboo forest ecosystems (Chen et al. 2009). Bamboo forests play a major role in the regional, national, and even global carbon balance (Xiao et al. 2010; Liu et al. 2011; Tu et al. 2013). Quantifying RS and its source components in bamboo forest is important for estimating the carbon cycling and climatic systems. Approximately, 83% of the GPP of terrestrial ecosystems from ecosystem respiration return to the atmosphere and 30% to 80% comes from RS (Davidson and Janssens 2006; Law et al. 2002). The carbon release from RS is estimated to be 98 Pg C per year in 2008 (1 Pg C=1015g C) (Bond-Lamberty and Thomson 2010). This amount is more than ten times of that fossil fuel combustion (IPCC 2007). Over 70 genera of bamboo with over 1200 species globally and more than 80% bamboo species distributed in Asia (Dransfiled and Wldjaja 1995). Bamboo has been utilized as an essential resource and material for the life and culture of Asian people. The bamboo plant's growth rate is relatively high compared with other tree species (Llese and Weiner 1995). It means that bamboo plants could be an effective absorber of CO_2 that has induced global warming. If the plantation forests of bamboo can be well managed, they will be good plants for afforestation and a carbon sink. However, the distribution of bamboo roots and rhizomes is limited near the soil surface. A higher growth rate of bamboos would be associated with the greater underground biomass and the higher respiration rate of the underground parts. The high level of CO_2 in the soil would suppress photosynthesis in bamboo leaves (Wei et al. 2005). The bamboo forest ecosystem is part of the forest ecosystem. The distribution area of the bamboo forest is limited, but in somewhere, like south China, it has been cultivated with human management for a long time. As climate change has been taking significant effect on forest carbon budget, many researchers pay attention to the carbon budget in the bamboo forest. Moreover, cultivating management had a significant impact on the bamboo forest carbon budget. In this study, we modified a terrestrial ecosystem model named Integrated Biosphere Simulator (IBIS) according to the management of Lei bamboo forest. Some researchers reported that bamboo forests, such as the Mao bamboo forests, have more efficient carbon sequestration than typical temperate forests, like Chinese fire and mason pine, in southern China (Zhou and Jiang 2004). The advantage of bamboo forests in carbon sequestration will play an essential role in future climate change. Due to this, bamboo forests play a critical role in the regional, national, even global C cycle (Tu et al. 2013).

The present study aims to evaluate seasonal dynamics of soil respiration, to evaluate the relationship between soil respiration, its source components and environmental factors; and to assess soil properties of bamboo plantation which act as a carbon sink and source under climate change. Soil is an essential component in the bamboo forest ecosystem. In this study, the soil respiration rate in a bamboo plantation was affected by soil temperatures and soil moisture contents was assessed.

2. Material and Methods

2.1. Soil CO_2 emission measurements

The CO_2 emissions from the above selected five sampling sites were measured monthly for two years consecutively on a prefixed date between 9 to 12 hrs to reduce variability due to diurnal changes in soil temperature (Parkin and Kaspar 2003). The CO_2 emission was measured using Environmental Gas Monitor with an SRC-1 chamber attached to a data logger (Model No. EGM-4, PP System, Haverhill, MA, USA). The chamber was 15 cm in height, 10 cm in diameter, with a capacity to measure CO_2 emissions from 0 to 9.99 g CO_2 cm^{-2} h^{-1}. The chamber was tightly placed at the soil surface in each site until the data logger fully recorded CO_2 emission measurements. The EGM records about 27 observations of soil CO_2 emission at an interval of 4 seconds each and completes the process of CO_2 emission for one site in about two minutes. Simultaneously soil temperature was also measured adjoining the chamber at a depth ~15 cm using a probe (2.5 cm diameter) attached to the instrument. The gravimetric soil water content was measured near the chamber by collecting a soil sample from 0 to 15 cm depth each from all five sampling sites. The moist soil was then oven-dried at 110±2 ^oC, and water content was determined (Reynolds 1970). Following the suggested guidelines from the Indian meteorological department, the daily air temperature, rainfall, evaporation, sunshine, wind velocity were recorded on 24 hours basis, and Relative humidity and vapour pressure were recorded at 7.19 hrs and 14.19 hrs from a meteorological station located at a distance of 0.8 km and computed monthly.

The soil CO2 emission was calculated by

$$R\ (t\ CO_2\ ha^{-1}yr^{-1}) = \sum_{i=1}^{24} Ri * 10^4 * 24 * 30 * 10^{-3} * 12 * 10^{-3} \cdots\cdots\rightarrow \text{(Equation 1)}$$

Where R is the soil CO_2 emission (t CO_2 $ha^{-1}yr^{-1}$), Ri is the average monthly CO_2 emission rate (g CO_2 m^{-2} hr^{-1}), 10^4 is the unit conversion of m^2 to ha, the first 10^{-3} is the unit conversion of g to kg, whereas the second 10^{-3} is the unit conversion from kg CO_2 to t CO_2.

2.2. Soil organic carbon (SOC) stock calculation

The SOC stock was calculated by using the following equation as suggested by IPCC Good Practice Guidance (IPCC 2003) for Land Use, Land-Use Change and Forestry:

$$SOC = \sum_{Horizon=1}^{Horizon=n} ([SOC] * Bulk\ Density * Depth * (1 - C\ frag.) * 10)_{Horizon} \cdots\cdots\rightarrow \text{(Equation 2)}$$

Where SOC is the representative soil organic carbon content for the forest type and soil of interest (t C ha^{-1}), SOC horizon is the soil organic carbon content for a constituent soil horizon (t C ha^{-1}), [SOC] is the concentration of soil organic carbon in a given soil mass obtained from analysis $(kg\ soil)^{-1}$, Bulk density is the soil mass per sample volume (t m^{-3}), depth of horizon depth or thickness of soil layer in m, C Fragment is the percentage volume of coarse fragments/100, dimensionless.

3. Statistical analysis

The soil CO_2 emission recorded periodically was analyzed using STATISTICA 7.0 software. Soil CO_2 emission, environmental and soil parameters recorded every month from the same experimental site of *P. roxburghii* plantation were used for analysis. Therefore, statistical analysis is needed to accommodate the possible autocorrelation between measurements in different months for soil CO_2 emission within the same plot. The temporal patterns in the soil CO_2 emission rate for two years, the monthly data was plotted sequentially and subjected to time series analysis to check the autocorrelations. It indicated that the CO_2 emission rates were autocorrelated only at the previous month and not the other months. Univariate ANOVA consequently analyzed the effects of soil CO_2 emission rates, microclimatic variables, and environmental and soil parameters. The month was considered an independent factor, and soil emission rate, soil moisture, soil temperature, air temperature and rainfall were dependent factors. Univariate ANOVA was performed to study the seasonal effect and examine the significance of differences, which was further evaluated using *post hoc* Tukey's test. Pearson correlation was calculated to test the relationships between monthly average soil CO_2 emission rates and microclimatic, environmental and soil properties. It is also Pearson's (product-moment) correlation coefficient and performed to check how CO_2 emission rates were related with different environmental parameters up to a specified period (correlations with environmental parameters from the day of initial CO_2 emission data recording and up to its 15th preceding day). Pearson correlation coefficient was determined for various parameters at 1% and 5% levels of significance. Regression analysis was also performed to model the relationship between emission rate and soil moisture, air temperature, and rainfall.

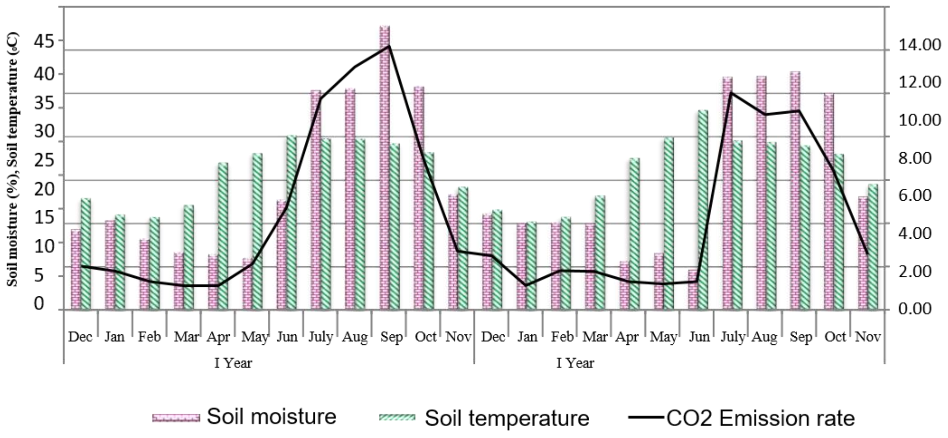


Figure 1. Monthly variation in soil CO_2 emission rates with soil temperature and soil moisture under *B. tulda* plantation

4. Results

4.1. Effect of soil moisture and soil temperature on carbon dioxide emission from soils under *B. tulda*

The results obtained on carbon dioxide emission from soil under *B. tulda* showed that the minimum CO_2 emission rates of 1.148 and 1.153 µmol CO_2 m^{-2} sec^{-1} were during April and January first, the second year of study, respectively (Figure 1). The *post hoc* Tukey's test revealed that CO_2 emission rates recorded in December to May were significantly different from rates of July to September during the first year observation. The maximum emission of 12.17 and 10.038 µmol CO_2 m^{-2} sec^{-1} was observed during September and July in the first and second years of study, respectively. CO_2 emission rates recorded in December to June were significantly different from July to September in the second year. The minimum soil moisture of 8.27 and 6.02±0.76 per cent was observed during April and June of the first and second year, respectively. The soil moisture recorded in September was significantly different from other months except for July, August and October in the first year. The maximum values of per cent soil moisture were 42.14 and 35.39 recorded during September in both the respective years. During the second-year soil moisture recorded in July to

October was significantly different from other months in the second year. The soil temperature was recorded at its minimum level 13.86 and 13.18 °C during February and January of the first and second years of study. The soil temperature recorded in April to June during the first year was significantly different from other months. It reached the maximum value of 25.96 and 29.7 °C in June during both the respective years. In the second- year maximum soil temperature was recorded in June and was significantly different from other months (Table 1).

Table 1: Monthly variations in mean soil CO_2 emission and soil micro climatic variables under *B. tulda* plantation in the study area (μ mol $CO_2m^{-2}sec^{-1}$)

Month	CO_2 Emission Rate	Soil Moisture (%)	Soil Temperature (°C)
December, 2016	2.040^{a} (0.151)	12.01^{ab} (1.150)	16.64^{d} (0.105)
January, 2017	1.816^{a} (0.124)	13.32^{abc} (0.738)	14.23^{ab} (0.144)
February, 2017	1.330^{a} (0.070)	10.64^{a} (0.889)	13.86^{ab} (0.138)
March, 2017	1.150^{a} (0.170)	8.61^{a} (0.901)	15.66^{cd} (0.154)
April, 2017	1.148^{a} (0.110)	8.27^{a} (0.241)	21.94^{g} (0.176)
May, 2017	2.152^{a} (0.418)	9.01^{a} (0.838)	23.31^{ghi} (0.329)
June, 2017	4.756^{ab} (0.516)	16.39abcde (1.437)	25.96^{l} (0.305)
July, 2017	9.761^{bc} (3.135)	32.57^{cdef} (2.958)	25.48^{kl} (0.267)
August, 2017	11.225^{c} (2.138)	32.85^{cdef} (2.837)	25.42^{kl} (0.100)
September, 2017	12.174^{c} (1.472)	42.14^{f} (4.805)	24.71^{jkl} (0.068)
October, 2017	6.996^{abc} (1.200)	33.15^{cdef} (2.926)	23.44^{hij} (0.067)
November, 2017	2.732^{a} (0.259)	17.17abcde (1.371)	18.33^{ef} (0.124)
December, 2017	2.520^{a} (0.247)	14.31^{abcd} (1.664)	14.97^{bc} (0.175)
January, 2018	1.153^{a} (0.085)	12.89^{abc} (0.997)	13.18^{a} (0.288)
February, 2018	1.831^{a} (0.465)	13abc (0.313)	13.9^{ab} (0.217)
March, 2018	1.802^{a} (0.290)	12.88^{abc} (1.196)	17.04^{de} (0.143)
April, 2018	1.334^{a} (0.122)	7.3^{a} (0.719)	22.6^{gh} (0.487)
May, 2018	1.225^{a}	8.46^{a}	25.62^{kl}

	(0.210)	(1.191)	(0.433)
June, 2018	1.334^{a}	6.02^{a}	29.7^{m}
	(0.166)	(0.761)	(0.736)
July, 2018	10.038^{bc}	34.57^{def}	25.2^{kl}
	(2.242)	(4.432)	(0.194)
August, 2018	9.033^{bc}	34.72^{ef}	24.95^{kl}
	(2.363)	(3.698)	(0.060)
September, 2018	9.025^{bc}	35.39^{ef}	24.46^{ijk}
	(0.739)	(4.042)	(0.211)
October, 2018	6.458^{abc}	32.16^{bcdef}	23.21^{ghi}
	(1.828)	(3.896)	(0.180)
November, 2018	2.590^{a}	20.73^{abcde}	18.74^{f}
	(0.161)	(1.457)	(0.155)
F	**10.37**	**24.66**	**351.7**
p-value	**<0.05**	**<0.05**	**<0.05**
S/NS	**S**	**S**	**S**

Note: Means with same superscripts are not significantly different; S: Significant, NS: Non significant at 5% level of significance; Values in brackets are standard errors of respective means.

4.2. Annual CO_2 emission and carbon stock in *B. tulda* plantation

The annual average CO_2 emission from *B. tulda* plantation during the first and second year was 65.32 and 55.13 t CO_2 ha^{-1} yr^{-1} respectively. Similarly, the carbon stock *B. tulda* plantations was recorded as 111.91 and 107.97 t ha^{-1}during first and second years.

4.3. Influence of air temperature and rainfall on average monthly and seasonal soil CO_2 emission

The average of two-year results reported that soil temperature (~25 ^{0}C) attained stability from June to September in both the years. Maximum soil moisture (38.77 %) were recorded in September and minimum soil moisture (33.57 %) tends to increase from July. The mean soil moisture values were statistically not-significant ($p>0.05$) for the rainy season and were significantly different ($p<0.05$) for the summer and winter seasons. Minimum CO_2 efflux rate was recorded during April (1.24 µmol CO_2 m^{-2} s^{-1}) and found significantly different ($p>0.05$) for the rates recorded during November to June. The maximum efflux rates were recorded during September (10.60 µmol CO_2 m^{-2} s^{-1}), which was significantly different from the other months ($p<0.05$) (Table 2).

Table 2: Average monthly (two years) variations in CO_2 emission rate, soil microclimatic variables in *B. tulda* vegetation

Month	**CO_2 Emission Rate (μmol $CO_2 m^{-2} s^{-1}$)**	**Moisture (%)**	**Soil Temperature (^{O}C)**
December	2.28a (0.158)	13.16ab (1.027)	15.80b (0.293)
January	1.48^{a} (0.131)	13.10^{ab} (0.589)	13.70^{a} (0.232)
February	1.58^{a} (0.237)	11.82^{ab} (0.593)	13.88^{a} (0.121)
March	1.47^{a} (0.192)	10.75^{ab} (1.001)	16.35^{b} (0.249)
April	1.24^{a} (0.083)	7.79^{a} (0.392)	22.27^{d} (0.268)
May	1.69^{a} (0.269)	8.74^{a} (0.697)	24.46^{ef} (0.462)
June	3.04^{ab} (0.625)	11.21^{ab} (1.890)	27.80^{g} (0.725)
July	9.90^{cd} (1.817)	33.57^{c} (2.534)	25.34^{f} (0.162)
August	10.13^{cd} (1.546)	33.78^{c} (2.219)	25.18^{f} (0.096)
September	10.60^{d} (0.922)	38.77^{c} (3.166)	24.59^{ef} (0.060)
October	6.73^{bc} (1.034)	32.65^{c} (2.303)	$23.32^{de\backslash}$ (0.098)
November	2.66^{a} (0.146)	18.95^{b} (0.944)	18.53^{c} (0.116)
F	**21.15**	**47.51**	**273.32**
p-value	**<0.05**	**<0.05**	**<0.05**
S/NS	**S**	**S**	**S**

Note: Means with same superscripts are not significantly different; S: Significant at 5% level of significance, NS: Non significant, Standard Error values in parentheses.

Soil CO_2 emission rates were varied seasonally, the increase in air temperature were observed during summer and monsoon seasons (23.67°C to 24.60°C). Statistically, the air temperature values recorded between different seasons were non-significant. Air temperature recorded during winter and rainy season (2.00 to 9.34 μmol CO_2 m^{-2} s^{-1}) were significantly different. Maximum rainfall leads to maximum soil CO_2 emission (9.34 μmol CO_2 m^{-2} s^{-1}) in monsoon season due to increase in soil moisture. Comparatively minimum emission rates were recorded during winter and summer seasons (Table 3/ Figure 2).

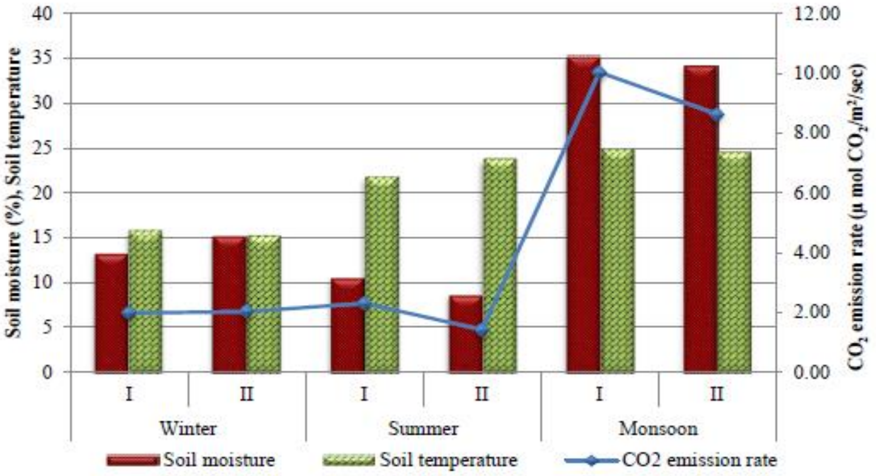


Figure 2: Seasonal variation in soil CO_2 emission rate with soil temperature and soil moisture in *B. tulda* plantation

Table 3: Seasonal variations in soil CO_2 emission rate with soil microclimatic variables in *B. tulda* plantation

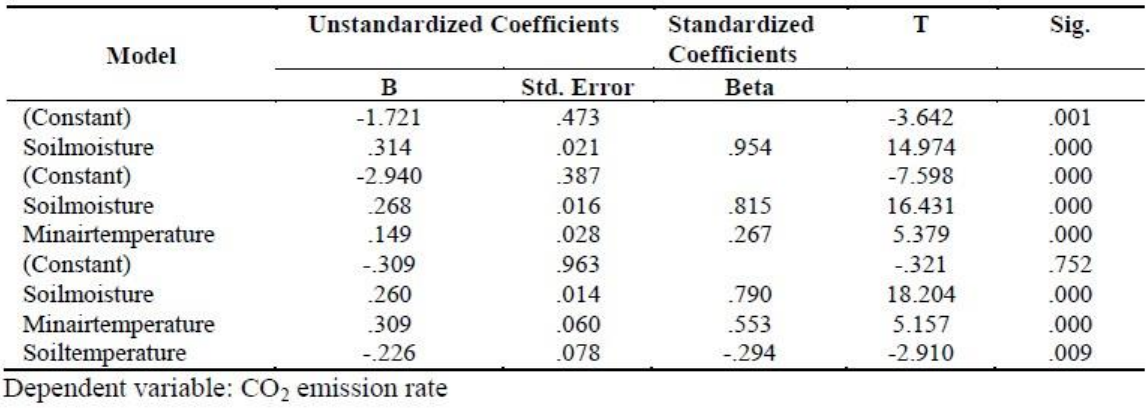
Season	Year	CO_2emission rate (µ mol $CO_2m^{-2}sec^{-1}$)	oil Moisture (%)	Soil emperature (^0C)	Air emperature (^oC)	Rainfall (mm)
Winter (November-February)	**I**	1.98^a (0.138)	13.29^{ab} (0.741)	15.77^a (0.423)	14.98^a (0.348)	0.40^a (0.110)
	II	2.02^a (0.185)	15.23^b (0.670)	15.20^a (0.501)	14.71^a (0.431)	0.52^a (0.029)
	Mean	**2.00 (0.161)**	**14.26 (0.705)**	**15.48 (0.462)**	**14.84 (0.389)**	**0.45 (0.069)**
Summer (March – June)	**I**	2.30^a (0.374)	10.57^{ab} (0.925)	21.72^b (0.876)	23.41^b (0.747)	3.37^a (0.777)
	II	1.42^a (0.107)	8.67^a (0.746)	23.74^{bc} (1.083)	23.95^b (0.654)	2.16^a (0.642)
	Mean	**1.86 (0.240)**	**9.62 (0.835)**	**22.73 (0.979)**	**23.67 (0.700)**	**2.76 (0.709)**
Rainy (July – October)	**I**	10.039^b (1.072)	35.178^c (1.845)	24.763^c (0.200)	24.89^b (0.354)	12.02^b (1.669)
	II	8.639^b (0.926)	34.210^c (1.127)	24.455^c (0.186)	24.33^b (0.510)	14.88^b (2.342)
	Mean	**9.34 (0.999)**	**34.70 (1.486)**	**24.61 (0.193)**	**24.60 (0.432)**	**13.44 (2.005)**
F		**40.655**	**46.773**	**94.190**	**83.16**	**25.39**
p-value		**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**
S/NS		**S**	**S**	**S**	**S**	**S**

4.4. Multiple linear regression (MLR) for soil CO_2 emission rates under *B. tulda* plantation

To see which of the variables influenced the soil CO_2 emission rates in *B. tulda* plantations, backward multiple linear regression analysis was performed. The model obtained by regression analysis indicated that soi moisture, soil temperature and minimum air temperature may be the main dominant (best predictor) variable for CO_2 emission (Table 4). The model and the adjusted R^2 value obtained are given below:

$$CO_2 \text{ emission Rate} = -0.309 + 0.260SM + 0.309MinAT - 0.226ST; \text{ Adjusted } R^2 = 0.970 \longrightarrow \text{(Equation 3)}$$

Table 4: Multiple linear regressions for soil CO_2 emission in *B. tulda* plantation



Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	-1.721	.473		-3.642	.001
Soilmoisture	.314	.021	.954	14.974	.000
(Constant)	-2.940	.387		-7.598	.000
Soilmoisture	.268	.016	.815	16.431	.000
Minairtemperature	.149	.028	.267	5.379	.000
(Constant)	-.309	.963		-.321	.752
Soilmoisture	.260	.014	.790	18.204	.000
Minairtemperature	.309	.060	.553	5.157	.000
Soiltemperature	-.226	.078	-.294	-2.910	.009

Dependent variable: CO_2 emission rate

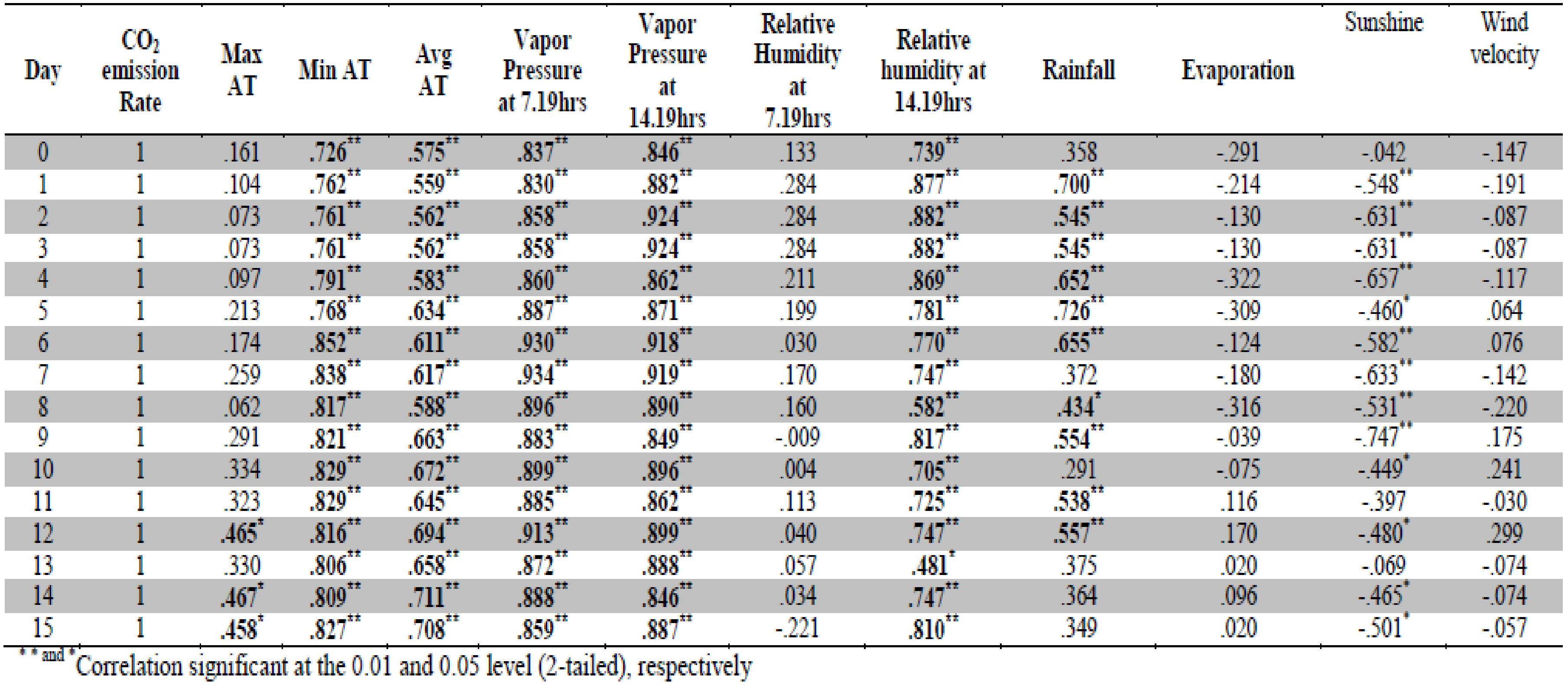
4.5. Correlation of soil CO_2 emission with different environmental parameters under *B. tulda* plantation

The Correlation Coefficient analysis results implies that soil CO_2 emission rates was significant and positively correlated with some variables like minimum air temperature, average air temperature, vapour pressure, relative humidity during the lag period of preceding 15 days of data recording. Results revealed that, significant positive correlation was observed with rainfall, a significant negative correlation with sunshine and a non- significant correlation with evaporation, initially for the preceding seven days of emission recording. It indicates that CO_2 emission rates were significantly affected by the air temperature, vapour pressure and rainfall over the preceding 15 days. Relative humidity measured during 14.19 hrs also showed a significant positive correlation with emission rate, but relative humidity measured at 7.19 hrs does not affect the emission rate (Table 5).

4.2. Soil properties in *B. tulda*

The soil analysis indicated that sandy clay loam textural class with proportion of sand (62.36 %), silt (12.8 %), clay (24.84 %), pH (5.99) and bulk density (1.17 $g^{-1}cm^{-3}$). The chemical properties revealed that Av. N (0.028%), Av. P (0.001%), and the Ex. K (0.017%) indicating that soil nutrients were medium to high. There was no significant monthly variation observed between different nutrients studied. The Pearson - correlation analysis was performed to check the relationship between soil properties and soil CO_2 emission rates. The results implies that the annual soil CO_2 emission rate was significant and positively correlated with micro climatic and environmental parameters. The annual emission rate was non-significant and showed a no correlation ($p > 0.05$ and $p > 0.01$) with some soil properties like soil organic carbon, potassium and nitrogen and a negative correlation with phosphorous (Table 6).

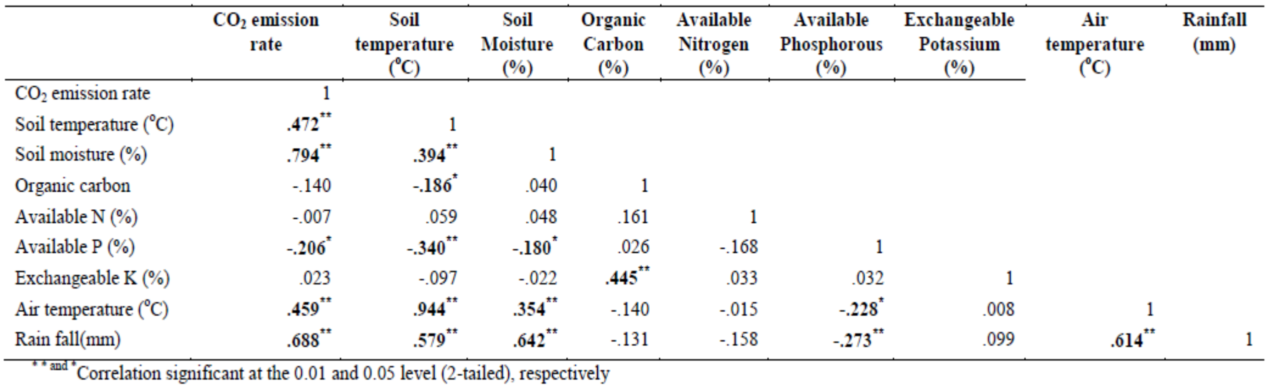
Table 5: **Correlation analysis (Pearson) of soil CO_2 emission rates and other environmental factors under *B. tulda* plantation in the study area.**



Day	CO_2 emission Rate	Max AT	Min AT	Avg AT	Vapor Pressure at 7.19hrs	Vapor Pressure at 14.19hrs	Relative Humidity at 7.19hrs	Relative humidity at 14.19hrs	Rainfall	Evaporation	Sunshine	Wind velocity
0	1	.161	.726**	.575**	.837**	.846**	.133	.739**	.358	-.291	-.042	-.147
1	1	.104	.762**	.559**	.830**	.882**	.284	.877**	.700**	-.214	-.548**	-.191
2	1	.073	.761**	.562**	.858**	.924**	.284	.882**	.545**	-.130	-.631**	-.087
3	1	.073	.761**	.562**	.858**	.924**	.284	.882**	.545**	-.130	-.631**	-.087
4	1	.097	.791**	.583**	.860**	.862**	.211	.869**	.652**	-.322	-.657**	-.117
5	1	.213	.768**	.634**	.887**	.871**	.199	.781**	.726**	-.309	-.460*	.064
6	1	.174	.852**	.611**	.930**	.918**	.030	.770**	.655**	-.124	-.582**	.076
7	1	.259	.838**	.617**	.934**	.919**	.170	.747**	.372	-.180	-.633**	-.142
8	1	.062	.817**	.588**	.896**	.890**	.160	.582**	.434*	-.316	-.531**	-.220
9	1	.291	.821**	.663**	.883**	.849**	-.009	.817**	.554**	-.039	-.747**	.175
10	1	.334	.829**	.672**	.899**	.896**	.004	.705**	.291	-.075	-.449*	.241
11	1	.323	.829**	.645**	.885**	.862**	.113	.725**	.538**	.116	-.397	-.030
12	1	.465*	.816**	.694**	.913**	.899**	.040	.747**	.557**	.170	-.480*	.299
13	1	.330	.806**	.658**	.872**	.888**	.057	.481*	.375	.020	-.069	-.074
14	1	.467*	.809**	.711**	.888**	.846**	.034	.747**	.364	.096	-.465*	-.074
15	1	.458*	.827**	.708**	.859**	.887**	-.221	.810**	.349	.020	-.501*	-.057

** and *Correlation significant at the 0.01 and 0.05 level (2-tailed), respectively

Table 6: **Correlation Analysis on CO_2 emission rate with other physico-chemical and environmental parameters under *B. tulda* in study. area**



	CO_2 emission rate	Soil temperature (°C)	Soil Moisture (%)	Organic Carbon (%)	Available Nitrogen (%)	Available Phosphorous (%)	Exchangeable Potassium (%)	Air temperature (°C)	Rainfall (mm)
CO_2 emission rate	1								
Soil temperature (°C)	**.472****	1							
Soil moisture (%)	**.794****	**.394****	1						
Organic carbon	-.140	**-.186***	.040	1					
Available N (%)	-.007	.059	.048	.161	1				
Available P (%)	**-.206***	**-.340****	**-.180***	.026	-.168	1			
Exchangeable K (%)	.023	-.097	-.022	**.445****	.033	.032	1		
Air temperature (°C)	**.459****	**.944****	**.354****	-.140	-.015	**-.228***	.008	1	
Rain fall(mm)	**.688****	**.579****	**.642****	-.131	-.158	**-.273****	.099	**.614****	1

** and *Correlation significant at the 0.01 and 0.05 level (2-tailed), respectively

5. Discussion

5.1. Soil CO_2 emission

The soil CO_2 emission rates documented during the first year were higher than the second year in the present study due to lower soil and air temperature during the second year. It is also reported that 10 per cent loss of organic carbon occurs due to increase in 1^0C temperature (Kirschbaum 1995). Regions with a MAT of 30^0C, lead to 3 % loss of organic carbon with rise in 1^0C temperature. Similar variations were observed in present investigation in CO_2 emission rates during the first and second years. The soil CO_2 emission rate recorded during the winter and summer seasons was significantly different ($p<0.05$) from the rainy season rates.

The main factor controlling the temporal variation of soil CO_2 emission rate is soil temperature. Similar results also reported a linear relationship between soil CO_2 emission rate and soil temperature (r^2= 0.58 and 0.33 respectively) (Kutsch and Kappen 1997). The exponential relationship between soil respiration and the soil temperature has been reported earlier (Yu et al. 2011). The differences in soil temperature in the forest may due to differences in plant growth and soil microbial activities (Chen et al. 2010). Similar variation in soil CO_2 emission rate due to soil temperature and soil moisture also observed in *P. roxburghii* plantations (Sivaranjani and Panwar 2021).

The increased amount and activity of microbial communities further promote organic matter decomposition, accelerating soil respiration rates, and subsequently, SOC reduction. Wardle et al (1998) confirmed that lower pH could accelerate microbial biomass turnover and higher pH reduced microbial biomass turnover rate, extending turnover time. Pearson's (product-moment) correlation coefficient for different environmental parameters revealed a significant positive correlation with minimum air temperature, rainfall and average air temperature during the lag period of preceeding 15 days of data recording (Table 5). It may be indicated to the sandy clay loam soil texture where *B. tulda* plantations have grown. Maximum plant available water stored in loamy textured soils and draining may take two to three days depending upon the medium to fine-textured soils.

5.2. SOC Sequestration

The present findings on average SOC pool under *B. tulda* (109.94 Mg ha^{-1}) are similar to Vanlalfakawma et al (2014), who reported higher soil carbon pool variation in the *Dendrocalamus longispathus* forest of Mamit (84.23 Mg ha^{-1}) and Kolasib (65.82 Mg ha^{-1}). Bulk density is the critical factor affecting the soil organic carbon pool for the particular area. Although, moisture and temperature play a significant role in the global carbon cycle. Organic carbon stocks result from the balance between inputs and outputs of carbon within the ground environments (Davidson and Janssens 2006). Wang et al (2009) estimated that the SOC stock in the upper 30 cm layer decreased, and approximately 10 and 25 per cent of original SOC emitted from grasslands over 28 and 42 years, respectively. The composition of forest stand influences the soil and ground cover, rate of tree growth (Bhatnagar 1965). Vegetation was the primary source of soil organic matter, which influences the soil characteristics such as pH, texture, nutrient availability and water holding capacity. The soil profile, pH, and nutrient cycling between the soils and plants are essential to determining the forest site quality. Thus, it helps in improving the soil structure, infiltration rate, water holding capacity and aeration (Kumar et al. 2004). Among the different physicochemical parameters studied, soil texture is one of the most important factor, which affects growth of microbial propagules and responsible for air and moisture, affecting CO_2 formation (Rastogi et al. 2002). The soil texture found in present study area was sandy clay loam under *B. tulda*, has higher emission rates as compared to other textural classes; as also observed by Kowalenko and Ivarson (Kowalenko and Ivarson 1978). Results of the studies indicated that higher soil CO_2 emission from clay loam soil (6.2 kg CO_2 ha^{-1} d^{-1}) and lower soil CO_2 emission from sandy soil (3.3 kg CO_2 ha^{-1} d^{-1}). Variation in climate and weathering process, vegetation cover, topography, microbial activities and several other biotic and abiotic variables leads to variation in soil characteristics. Vegetation plays an essential role in soil formation. The plant tissues from forest floor through litter (aboveground and belowground root detritus) are the primary source of soil organic matter, which influences the physio-chemical characteristics of soil such as pH, texture, water holding capacity and nutrient availability (Johnston 1986).

5.3. Soil Properties

Nitrogen is a key element essential for plant growth in terrestrial ecosystems (Xia and Wan 2008). The available nitrogen content was higher in *B. tulda* (0.028 %). The nitrogen content depends to a large extent upon the amount and properties of organic matter. Enrichment of soil with nitrogen, improved the soil fertility (Gupta and Sharma 2008; 2009). Similar nitrogen contents were also reported by Paudel and Sah (2003). Nitrogen normally lost through leaching and run-off process. It has also been reported that soil respiration rates were positively correlated with nitrogen contents and negatively correlated with soil organic carbon (Table 6), which is inconsistent with the results obtained for present investigation (Tang et al. 2016). The higher soil respiration rate and lower soil organic carbon were recorded during first year of study. The soil organic carbon decrease may due to intensive forest management, increased carbon mineralization led to maximum soil carbon dioxide emission rate (Guo-Mo et al. 2006). Soil properties potentially affect the soil respiration rates (Chen et al. 2010).

The pattern of phosphorous availability in soils of different vegetation cover showed an average mean value of 0.001 %. The mean available phosphorous was observed medium to high in the vegetations studied. However, the availability of phosphorous varied dramatically among the forest vegetations. Available phosphorous content of 76.64 to 79.29 kg/ha in pure and mixed *S. robusta* forest was reported by Paudel and Sah (2003). Phosphorous is the second most crucial soil nutrient limiting vegetation production and occupies a key position in metabolism. Pandey et al (2018) reported the phosphorous content (62 mg/kg) in pine vegetation. Nitrogen fixation also influenced by phosphorus availability and carbon: nitrogen ratio in the litter, influencing its decomposition rate. The available phosphorous values obtained from the present study were similar to the Riyale forest results (Shrestha 1996) and higher than the Nagarkot forest (Juwa 1987). However, it was very close to the value reported for the Chitrepani forest [40] and coincided with the findings of Bhatnagar (1965).

The mean value of exchangeable potassium obtained in the present study under different vegetation cover was *P. roxburghii* (329.65 kg/ha), *S. robusta* (448.18 kg/ha), *B. tulda* (392.23 kg/ha) and Grassland (233.89 kg/ha) (Table 4.36). According to Bhatnagar (1965), soil containing higher potassium helps in good regeneration. The value was higher than that (329.57- 399 kg/ha) reported in KoshiTappu Wildlife Reserve (Karki 1999) and higher than the value (41.01-87.79 kg/ha) reported in two sal forests in the hills of Kavreplanchowk (Pant 1997) and the value of 86.40-262.8 kg/ha as reported in *S. robusta* forest in Chitrepani (Shrestha 1997).

Potassium performs vital processes like regulating transpiration and respiration, influencing enzyme action and helping in the synthesis of carbohydrates and proteins etc., (Brady 2000). Potassium was not influenced by soil organic matter because organic matter is not the direct supplier of potassium. Potassium was found as part of the mineral structure of many clay minerals, particularly micas. However, potassium is locked up from plant roots (Regmi and Zoebisch 2004). Joshi et al (1999) reported that exchangeable potassium was higher in surface layers than subsurface layers. The exchangeable potassium range from 233.86 to 267.73 kg/ha was observed by Paudel and Sah (2003).

Soil organic matter governs its physicochemical characteristics and provides favourable conditions for the survival of functional groups (Horwath 2005). Therefore, the lowering in the soil organic matter in vegetation cover directly depletes the concentration of essential nutrients. Additionally, variation in the accessibility of nutrients is also affected by the pattern of forest succession responsible for the difference in organic matter content (Chandra et al. 2016).

Conclusion

The study gives a better estimation of the soil CO_2 emission rate and carbon sequestration rate of *B. tulda* plantation and contributes to estimate carbon balance across different forest types. Soil respiration and its source components varied across seasons, mainly in response to soil temperature and moisture changes and their interactions. It is also found that the soil CO_2 emission rate in the bamboo forest floor was greater than those other forests types and the main source for CO_2 production rate in the bamboo forest floor was roots and rhizomes of bamboo. The monthly and seasonal variations of soil CO_2 emission rate in bamboo plantations is the important factor for predicting the carbon balance in bamboo plantation. It is considered that the higher growth rate of bamboos would be associated with the greater underground biomass and the higher respiration rate of the underground parts. In conclusion, the soil respiration rate significantly increased with the rise in the soil temperature and soil moisture in the bamboo forest.

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Conflict of Interest

The authors declare there is no conflict of interest

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