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RESEARCH ARTICLE

Changes in Soil and Weather Variables at Different Plantation Forests in Nagaland, India

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Abstract The present study was undertaken to determine soil respiration and its relation with some soil or weather variables under pine plantation forest located at Atoizu town (Zunheboto district), bamboo plantation at Khensa village (Mokokchung district) and rubber plantation in Yongam village (Longleng district) of Nagaland. The maximum soil respiration was recorded during winter while the minimum value was exhibited during the rainy season both from rubber plantation. Soil respiration was positively correlated with atmospheric temperature, soil temperature and pH in all the sites. Among all the parameters, only soil bulk density was significantly different between the three plantation sites (Pine-rubber, pine-bamboo and rubber-bamboo). Overall, the results obtained from the experiments provided a better understanding of soil respiration affinity with soil or weather variables under pine, bamboo and rubber forest which would ultimately help researchers in improving the efforts to quantify the carbon sink potential in these pockets of ecosystem.

Keywords Plantation forest · Soil respiration · Soil properties · Weather variables

Significance Statement: Different types of forests impart diverse ecosystems and play a significant role in carbon sequestration including global climate regulation. Thus, the study highlights the variation of soil respiration in respect to some environmental variables under pine, bamboo and rubber plantation forest stands in Nagaland.

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Introduction

With the exception of gross photosynthesis, carbon dioxide emissions from soils (soil respiration) outnumber all other terrestrial-atmospheric carbon exchanges [1]. Every year, over ten percent of the CO_2 in the atmosphere flows through soils: this is more than ten times the CO_2 released by fossil fuel combustion. Because of the magnitude of the soil-to-atmosphere CO_2 flux and the large pool of potentially mineralizable carbon in soils [2], any increase in soil CO_2 emissions in response to environmental change has the potential to exacerbate rising atmospheric CO_2 levels causing worldwide global warming. In order to analyze the possible repercussions of environmental changes, it is required to first identify the environmental parameters that govern soil CO_2 emissions and their effects on emission rates. Abiotic variables such as soil temperature and moisture conditions of a region play an important role in determining the rates of soil respiration [3]. It is estimated that climatic differences generate variations in soil respiration rates among distant sites and soil microclimate plays an important role in redefining seasonal changes in soil CO_2 emissions within sites [4]. Soil respiration rates vary greatly between major biome types, and comparisons of different plant communities usually reveal variances in soil respiration rates [1]. Such findings indicate that vegetation type is an important determinant of soil respiration rate, and therefore, changes in vegetation structure have the potential to modify the responses of soils respiration to environmental factors. Various researchers have worked on soil CO_2 flux in different ecosystems of the world viz., temperate forest [5], tropical forest [6], sub-tropical montane forest [7], tropical savannahs [8], bamboo forest ecosystems [9] and grassland ecosystem [10]. Northeast India, in particular, Nagaland, though situated in Indo Burma biodiversity hotspot, still has a notable

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lack of studies on soil respiration in relation to pine, bamboo and rubber plantation forest. Given the importance of soil respiration in quantifying net ecosystem productivity and forest carbon sequestration, an attempt has been undertaken to evaluate monthly and seasonal dynamics of soil respiration in pine, rubber and bamboo plantations, to investigate the physicochemical properties of soil and to determine the factors affecting the relationship between soil respiration and some selected soil or weather variable in the three forest stands.

Material and Methods

Study Area

Nagaland, a state in North-eastern India, has a sub-tropical monsoonal type of climate with annual rainfall varying from 100 to 300 cm [11]. The types of forest in Nagaland are tropical moist deciduous forest, tropical semi-evergreen forest, sub-tropical broadleaved hill forest, sub-tropical pine forest and montane wet-temperate forest. For the present study, the seasons are categorized into summer, rainy and winter. The pine (*Pinus roxburghii*) plantation forest is located at Atoizu town under Zunheboto district (Latitude 26° 06.508′ N and Longitude 094° 31.160′ E) with an elevation of 1723 m above the sea level. Based on the geographical location, climate, topography and the types of dominant plant species, the study area falls under the tropical deciduous and mixed bamboo forest. The average age of pine plantation was about 20 years, and the litter thickness on the forest floor has been measured at around 10 cm. The experimental site of bamboo (*Dendrocalamus giganteus*) plantation is located in Khensa village under Mokokchung district at an altitude of 1035 m above mean sea level with coordinates of 26° 20.932′ N latitude and 94° 29.039′ E longitude. The forest falls under the Northern tropical semi-evergreen forest system. Rubber (*Hevea brasiliensis*) plantation site is geographically located at 26° 33.313′ N latitude and 094° 51.097′ E longitude, with an elevation of 510 m above the mean sea level in Yongam village, Longleng district. The region is characterized by sub-tropical mixed forests with broad-leafed evergreen and deciduous trees.

Estimation of Soil Produced Carbon Dioxide

CO_2 production from the forest floor soil under the three plantations forest was measured monthly during the time period 8.30 to 9.30 AM from September 2018 to May 2019 by using the Alkali trap method [12]. Original and duplicate readings were taken from ten randomly chosen sites in each plot of the plantations and their arithmetic means were used for the present study.

Soil or Weather Variable Analyses

The Walkley and Black [13] titration method was used to measure organic carbon and matter. The core sampler approach, as described by Blake and Hartge [14], was used to estimate bulk density. A sampling core with a height of 10 cm and a diameter of 5.5 cm was used to measure the bulk density from 0 to 10 cm layer soil depth. By using a hygrometer (model HTC-2), the record of atmospheric temperature and relative humidity was noted down at the spot. Soil pH was determined using a digital pH meter (μ pH system 361, Serial no: 6835). Soil temperature was taken at the spot from a depth of 0–10 cm by using soil thermometer (Omsons, Narindra Scientific industries). Pearson's Correlation matrix was computed to find out the level of significance and correlation between soil respiration and other soil or weather variable. A sample paired *t* test was also statistically assessed between pine-rubber, pine-bamboo and rubber-bamboo plantation sites to determine any significant difference between the means of each parameter. Both of the statistics were performed using the software SPSS version 16.0.

Results and Discussion

Soil Respiration Under Pine, Rubber and Bamboo Plantation Forest

Table 1 represents the monthly variations of soil respiration and soil or weather variable in pine, rubber and bamboo plantations forest. Soil respiration, the carbon dioxide (CO_2) emission from the soil surface, is an important component of carbon balance in terrestrial ecosystems. Soil respiration originates from the products of both autotrophic respiration (root respiration) and respiration of root exudates by rhizospheric microbes as well as the heterotrophic respiration by soil microorganisms that decompose the organic matters [15]. During the study period, monthly variation of soil respiration was recorded maximum in October (279.44 mg CO_2 m^{-2} h^{-1}) at the bamboo plantation and minimum in May (80.10 mg CO_2 m^{-2} h^{-1}) from rubber plantation. Seasonal variation of soil respiration varies significantly in all the sites (Table 2). The average rate of soil respiration followed the trend 'pine plantation (184.71 mg CO_2 m^{-2} h^{-1}) > rubber plantation (153.44 mg CO_2 m^{-2} h^{-1}) > bamboo plantation (146.70 mg CO_2 m^{-2} h^{-1})'. Both the maximum and minimum soil respiration rates were obtained during winter and summer in rubber plantation with values of 225.85 and 101.32 mg CO_2 m^{-2} h^{-1}, respectively. Soil respiration rate in pine plantation was positively correlated with atmospheric temperature ($r = +0.500$), soil temperature ($r = +0.545$), relative humidity ($r = +0.369$) and bulk density ($r = +0.348$).

Table 1 Monthly variations in soil or weather variables at pine, rubber and bamboo plantation

Forest	Sept. 2018	Oct	Nov	Dec	Jan. 2019	Feb	Mar	Apr	May
Soil respiration (mg CO_2 m^{-2} h^{-1})									
Pine	119.25	279.44	202.56	99.97	91.53	250.54	261.38	172.24	185.50
Rubber	172.27	120.45	96.36	221.63	264.99	96.36	132.53	96.30	80.10
Bamboo	126	253	205	204	240	169	133	108	83
Atmospheric temperature (°C)									
Pine	19.15	20.35	17.70	15.30	12.30	12.85	11.90	19.95	20.65
Rubber	27.90	23	19.40	17.10	11.10	15.80	21.70	26.67	27.9
Bamboo	21.60	23.50	18	13.50	13	19.60	18.05	25.50	25
Soil temperature (°C)									
Pine	18.25	17.50	13.50	11.00	10.50	11.50	9.50	13.50	15.00
Rubber	25	23	19	14	11	10	18	20.10	24
Bamboo	21.50	22.50	17	12.50	12	16.50	16	11.50	21
Relative humidity (%)									
Pine	80.00	84.5	44.50	32.00	58.00	57.00	63.00	42.00	60.50
Rubber	94	88	87	72	70	72	71	60	74
Bamboo	95.5	81.5	89	82	80	32.5	68.5	46	81
Soil pH									
Pine	5.60	5.07	5.02	6.06	5.90	6.58	5.70	6.35	5.36
Rubber	6.4	6.74	6.8	6.86	7.04	7.62	6.78	6.07	6.3
Bamboo	6.5	6.4	7.2	6.6	6.5	6.9	6.3	6.6	6.5
Organic carbon (%)									
Pine	2.82	2.52	2.34	1.02	1.92	1.26	1.86	1.92	2.70
Rubber	0.90	2.16	2.10	1.50	0.78	0.60	0.96	1.44	1.26
Bamboo	1.2	2.3	1	1.54	1.3	2.09	1.81	1.69	1.5
Organic matter (%)									
Pine	4.86	4.34	4.03	1.75	3.31	2.17	3.20	3.31	4.65
Rubber	1.55	3.72	3.62	2.58	1.34	1.03	1.65	2.48	2.17
Bamboo	2.06	4	1.72	2.65	2.2	3.6	3.12	2.9	2.5
Bulk density (g cm^{-3})									
Pine	1.76	1.66	1.58	1.57	1.71	1.95	1.77	1.67	1.72
Rubber	2.77	2.69	2.65	2.69	2.56	2.47	2.58	2.56	2.72
Bamboo	2.2	2.06	2.16	2.5	2.3	2.38	2.59	2.40	2.69

Table 2 Seasonal variations in soil or weather variables at pine, rubber and bamboo plantation

Parameters	Pine			Rubber			Bamboo		
	Rainy	Winter	Summer	Rainy	Winter	Summer	Rainy	Winter	Summer
Atmospheric temperature (°C)	19.15	16.41	16.33	27.9	17.7	23.02	21.6	17.00	22.03
Soil temperature (°C)	18.25	13.12	12.37	25	16.75	18.02	21.5	16.00	16.25
Relative humidity (%)	80.00	54.75	55.62	94	77.25	69.25	95.5	83.12	57.00
Bulk density (g cm^{-3})	1.76	1.63	1.77	2.77	2.62	2.58	2.20	2.25	2.51
Soil pH	5.60	5.51	5.99	6.4	6.86	6.69	6.5	6.7	6.6
Organic carbon (%)	2.82	1.95	1.93	0.9	1.63	1.06	1.2	1.5	1.8
Organic matter (%)	4.86	3.35	3.33	1.55	2.81	1.83	2.06	2.64	3.03
Soil respiration (mg CO_2 m^{-2} h^{-1})	119.25	168.37	217.41	72.27	225.85	101.32	126.00	225.50	123.25

In rubber plantation, it was positively correlated with atmospheric and soil temperature ($r = +0.595$; $r = +0.536$) whereas in bamboo plantation significant positive correlation values was obtained with atmospheric temperature ($r = +0.639$), organic carbon ($r = +0.334$), soil temperature ($r = +0.178$) and relative humidity ($r = +0.157$).

According to Kukumagi et al. [16], soil temperature was the most important element controlling seasonal dynamics of soil respiration, accounting for up to 75% of overall variation in soil respiration. Soil temperature and soil moisture are two of the most important environmental factors driving the seasonal and diurnal changes of soil respiration [17], and soil respiration is relatively sensitive to soil temperature [18]. This study is consistent with the results of Liu et al. [19] and Tang et al. [20], who observed a strong relationship between soil respiration with soil temperature in the Moso bamboo forests of sub-tropical China. As shown in Table 3, the sample paired t test exhibited no significant difference in soil respiration between the three plantation sites at the $p \leq 0.05$ level.

Soil or Weather Variable Under Pine, Rubber and Bamboo Plantations Forest

Bulk density is an important physical property of soil and is an index of soil compaction, which affects site productivity and forest growth. In the present study, bulk density was recorded maximum (2.77 gcm^{-3}) in rubber plantation during February and minimum in pine plantation (1.57 gcm^{-3}) during the month of December. The averaged values of bulk density in pine, rubber and bamboo plantations were 1.71, 2.63 and 2.50 gcm^{-3}, respectively. Seasonally, variation of bulk density was recorded maximum during rainy season (2.77 g cm^{-3}) in rubber plantation and minimum during the winter season in pine plantation (1.63 g cm^{-3}). Our observation of bulk density was comparatively higher than the value obtained by Bhaishya and Sharma [21] where they recorded an averaged value of 1.32 g cm^{-3} in rubber plantation. Plants and litter components present over the plantation floor play a major role in the formation of humus soil and tend to increase the bulk density of the soil. Bulk density in pine forest was found to be negatively correlated with soil temperature, atmospheric temperature, organic carbon and organic matter at $p \leq 0.01$. Bulk density in bamboo plantation was found to be negatively correlated with soil respiration, soil temperature, relative humidity, pH and organic matter at $p \leq 0.01$ and positively correlated with atmospheric temperature and organic carbon at $p \leq 0.01$ level. The t test of bulk density provided a significant difference between pine-rubber ($p=0.001$, $t=-18.57$), pine-bamboo ($p=0.001$, $t=-8.30$) and rubber-bamboo ($p=0.003$, $t=3.52$) exhibiting that different type of forest stands affects bulk density in its specific area.

Soil pH was recorded maximum in rubber plantation during February (7.62) and minimum was recorded in November (5.02) from pine plantation. Seasonally, the average pH was recorded highest during rainy season (6.86) in rubber plantation and minimum during winter in pine forest (5.51). The average values of soil pH in pine, rubber and bamboo plantations were 5.73, 6.73 and 6.6, respectively. A similar

Table 3 T test presenting overall mean value (± S.E), t and p value of soil or weather variables between different plantation sites

Parameters	Mean (± S.E)			t value			p value		
	Pine	Rubber	Bamboo	Pine-rubber	Pine-bamboo	Rubber-bamboo	Pine-rubber	Pine-bamboo	Rubber-bamboo
Soil respiration (mg CO_2 m^{-2} h^{-1})	184.71 ± 23.51	142.30 ± 21.41	169 ± 20.03	1.33	.509	−.909	.201	.618	.377
Atmospheric temperature (°C)	16.68 ± 1.21	21.17 ± 1.95	19.75 ± 1.53	−1.95	−1.57	.574	.068	.136	.574
Soil temperature (°C)	13.36 ± 1.02	18.23 ± 1.84	16.72 ± 1.40	−2.31	−1.93	.652	.034	.072	.524
Relative humidity (%)	57.94 ± 5.69	76.44 ± 3.61	72.89 ± 6.89	−2.74	−1.67	.457	.014	.114	.654
Soil pH	5.73 ± 0.18	6.73 ± 0.15	6.61 ± 0.09	−4.24	−4.32	.698	.001	.001	.495
Organic carbon (%)	2.04 ± 0.20	1.30 ± 0.18	1.60 ± 0.14	2.67	1.75	−1.31	.017	.099	.210
Organic matter (%)	3.51 ± 0.35	2.24 ± 0.31	2.75 ± 0.24	2.67	1.76	1.27	.017	.097	.223
Bulk density (g cm^{-3})	1.71 ± 0.03	2.63 ± 0.03	2.36 ± 0.06	−18.57	−8.30	3.52	.001	.001	.003

observation was made by Tripathi et al. [22] in the subtropical pine forest of Meghalaya. Several workers reported that the soil for most of the pine forests of the world was acidic in nature [23]. The canopy leachates, microorganisms' activities and the formation of humus due to decay of various forest litters may increase the acidity of the forest soil. Sample t test indicates that soil pH was significantly different between pine-rubber ($p=0.001$, $t=-4.24$) and pine-bamboo ($p=0.001$, $t=-4.32$) but no such valid difference was observed for rubber-bamboo.

Organic carbon content was maximum during September at pine plantation (2.82%) and minimum in February at rubber plantation (0.60%). Seasonal soil organic carbon was highest during rainy season (2.82%) in pine plantation and lowest during rainy season (0.9%) in rubber plantation. The average values of soil organic carbon in pine, rubber and bamboo plantations were 2.04, 1.30 and 2.04%, respectively. Organic carbon was found to be significantly positive with soil temperature at $p \leq 0.05$ and negatively correlated with pH and bulk density. The maximum rate of organic carbon during rainy season in pine plantation may be due to favorable temperature, sufficient rainfall and higher rate of litter and root decomposition [24]. The direct effect of the poor soil organic carbon in rubber plantation may be due to reduced microbial biomass activity and nutrient mineralization because of the shortage of energy sources. It may also be due to soil erosion which removes the top soil containing the bulk of soil organic matter. While the high value of soil organic carbon in pine plantation may be due to microbial activity and the humus content in the topsoil. No significant correlation exists between organic carbon and organic matter with soil respiration in rubber plantation while in bamboo plantation, organic carbon was negatively correlated with relative humidity ($r=+0.567$) and pH ($r=-0.364$) and positively correlated with soil respiration, atmospheric temperature and soil temperature at $p \leq 0.01$ level. Soil organic carbon variability was observed in all three plantations which could be due to the burning or clearing of forest litterfall and debris by local inhabitants at different intervals of time. These activities might have affected the organic matter present in the plantation forest soil and since organic carbon is directly proportional to the amount of organic contents in the soil its concentration may have fluctuated periodically. The t test exhibits pine-rubber plantation site to have a significant difference of $p=0.017$; $t=2.67$. However, pine-bamboo and rubber-bamboo showed no such indication at the $p \leq 0.05$ level of difference.

Soil organic matter enhances soil physical properties including soil aggregate stability, water holding capacity and soil bulk density [22]. Moreover, it serves as a substrate for soil respiration, and environmental parameters such as soil temperature and moisture are largely dependent on the energy released by soil organic matter decomposition [18]. Soil organic matter in pine forest was recorded maximum (4.86%) in September and minimum (1.03%) in February at rubber plantation. Seasonally, soil organic matter followed the same trend as organic carbon and recorded maximum during rainy season (4.86%) in pine plantation (4.86%) and minimum during rainy season in rubber plantation (1.55%). The averaged values of soil organic matter in pine, rubber and bamboo plantations were 3.53, 2.23 and 3.53%, respectively. McElligott [25] reported that the organic matter content was 5.43% at 0–10 cm soil depth in 25 age stand of Loblolly pine which was higher than our recorded value. Organic matter does not show a significant correlation with soil respiration in pine forest. However, in bamboo forest, it was positively significant with soil respiration ($r=+0.471$) and organic carbon at $p \leq 0.01$ level while negatively correlated with relative humidity and pH at $p \leq 0.01$ level (Table 4). In a bamboo plantation, rigorous bamboo shoot harvesting can speed up the decomposition of bamboo litter and the humification of the soil organic matter. Furthermore,

Table 4 Pearson's correlation matrix (r) between soil respiration and soil or weather variables in bamboo plantation forest

Parameters	Soil respiration	Soil temperature	Atmospheric temperature	Relative humidity	Organic carbon	Organic matter	Soil pH	Bulk density
Soil respiration	1							
Soil temperature	0.178	1						
Atmospheric temperature	0.639	0.529	1					
Relative humidity	0.157	0.398	0.707	1				
Organic carbon	0.334	0.175	0.318	−0.567	1			
Organic matter	0.471	0.346	0.111	−0.344	0.921**	1		
Soil pH	0.281	−0.137	−0.135	−0.146	−0.364	−0.33	1	
Bulk density	−0.619	−0.262	0.004	−0.257	0.018	−0.036	−0.29	1

*Correlation is significant at the 0.01 level

**Correlation is significant at the 0.05 level extensive bamboo management has the potential to promote the mineralization of labile organic carbon and enhance carbon dioxide emissions, i.e., soil respiration [19]. Similar to soil organic carbon, the organic matter showed no significant difference between pine-bamboo and rubber-bamboo at the $p \leq 0.05$ level but presented a significant difference between pine-rubber ($p = 0.017$; $t = 2.67$).

In most ecosystems, soil temperature is the most important abiotic factor regulating soil respiration, and it is extensively employed in soil respiration models. The factor by which soil respiration increases with each soil temperature is the feedback mechanism between the terrestrial carbon cycle and climate systems [26] and several field experiments have demonstrated that soil respiration becomes more sensitive to temperature as soil moisture increases [18]. The soil temperature is an important physical property that depends on the size, shape, arrangement and mineral composition of the soil and fluctuates throughout the year with the incident of solar radiation, rainfall, seasonal variations of overlying air temperature and the depth of the earth. Soil temperature in rubber plantation was recorded maximum in September with temperature rising to 25 °C, while minimum soil temperature was recorded in May at pine plantation (9.50 °C). Significant seasonal change in soil temperature was observed and exhibited highest during rainy season (25 °C) in rubber plantation and lowest during summer (12.37 °C) in pine plantation. The maximum recorded soil temperature during rainy season may be due to high atmospheric temperature which was in conformity with Florinsky et al. [27]. The average values of soil temperature in pine, rubber and bamboo plantations were 18.23, 18.23 and 16.6 °C, respectively. Kaspar and Bland [28, 29] reported that temperature of the surface soil layer is influenced by the fluctuations in air temperature near the ground and the decline in soil temperature with increasing soil depth depends to some extent on the metabolic activities of plant roots especially fine roots and microbes inhabiting in these layers. Soil temperature in rubber plantation was found to be positively significant with atmospheric temperature at $p \leq 0.01$; $r = +0.913$ and with soil respiration ($r = +0.536$) as reflected in Table 5. While in bamboo plantation soil temperature was recorded positively correlated with soil respiration ($r = +0.178$) and atmospheric temperature ($r = +0.529$) which was in conformity with Tang et al. [20]. Sampling paired t test showed that pine-rubber ($p = 0.017$; $t = 2.67$) presented a significant difference while such result was not indicated in pine-bamboo ($p = 0.072$; $t = -1.93$) and rubber-bamboo ($p = 0.524$; $t = 0.652$).

The highest (27.90 °C) and lowest (11.90 °C) recorded atmospheric temperature were noted in rubber plantation during September and January, respectively. Seasonally, atmospheric temperature was maximum in rubber plantation during rainy season (27.90 °C) and minimum in pine plantation (16.33 °C) during summer. The average values of atmospheric temperature conditions in pine, rubber and bamboo plantations were 16.68 °C, 21.17 °C and 19.5 °C, respectively. Atmospheric temperature in pine plantation was positively significant with soil temperature and soil respiration at $p \leq 0.01$, while in rubber plantation it was positively correlated with soil respiration ($r = +0.595$). On a global scale, soil respiration rates are substantially correlated with mean annual air temperatures and mean annual precipitation. The t test showed no significant difference in atmospheric temperature at the $p \leq 0.05$ level between the plantations. Reasonably, these sites are located under a geographical region influenced by similar climatic conditions and thus the atmospheric temperature did not vary markedly among the plantation sites.

Maximum atmospheric relative humidity was exhibited in bamboo plantation forest in September (95.50%) and minimum in pine plantation (32.00%) during December. Seasonally, atmospheric relative humidity was recorded maximum

Table 5 Pearson's correlation matrix (r) between soil respiration and soil or weather variables in rubber plantation forest

Parameters	Soil respiration	Atmospheric temperature	Relative humidity	Soil temperature	Soil pH	Organic carbon	Organic matter	Bulk density
Soil respiration	1							
Atmospheric temperature	.595	1						
Relative humidity	−.282	.230	1					
Soil temperature	.536	.913**	.502	1				
Soil pH	.260	−.816**	.004	−.798**	1			
Organic carbon	−.008	.226	.344	.439	−.324	1		
Organic matter	−.009	.227	.344	.440	−.325	1.000**	1	
Bulk density	.016	.565	.658	.762*	−.564	.413	.413	1

*Correlation is significant at the 0.01 level

**Correlation is significant at the 0.05 level

Table 6 Pearson's correlation matrix (*r*) between soil respiration and soil or weather variables in pine plantation forest

Parameters	Soil respiration	Atmosphere temperature	Relative humidity	Soil temperature	Soil pH	Organic carbon	Organic matter	Bulk density
Soil respiration	1							
Atmospheric temperature	.500	1						
Relative humidity	.369	.224	1					
Soil temperature	.545	.846**	.621	1				
Soil pH	.076	.056	.465	.284	1			
Organic carbon	.098	.666	.659	.773*	−.123	1		
Organic matter	.097	.089	.666	.773*	−.123	1.000**	1	
Bulk density	.348	−.390	.378	−.113	.404	−.120	−.119	1

*Correlation is significant at the 0.01 level

**Correlation is significant at the 0.05 level

in bamboo plantation (95.5%) during rainy season and minimum in pine plantation (55.62%) during winter. Atmospheric relative humidity in pine plantation was found to be positively correlated with soil temperature ($r = +0.621$) and soil respiration ($r = +0.369$) as shown in Table 6. Kukumagi et al. [16] revealed that humidification resulted to a dramatic increase in below-ground biomass and the production of the understory, while a 28% increase in the soil basal respiration of microbes. However, the above-ground biomass and root turnover rate of the understory remains almost constant. Hence, elevated atmospheric humidity significantly affects the carbon cycle of deciduous forest. Atmospheric humidity of bamboo plantation was found to be positively correlated with atmospheric temperature ($r = +0.707$) and soil temperature ($r = +0.398$) due to their tendency to influence each other state in the environment and regulate the thermal properties of the forest stands. The paired *t* test showed a significant difference between pine-rubber ($p = 0.014$; $t = -2.74$) while such observation was notably not detected for pine-bamboo and rubber-bamboo at the $p \leq 0.05$ level.

Conclusion

The study conducted on pine, bamboo and rubber plantations sites revealed that soil and weather variables like bulk density, soil pH, organic carbon and relative humidity vary significantly between sites and were relatively site-specific. Moreover, soil respiration rate in the pine stands was formidably controlled by atmospheric temperature and relative humidity; in the rubber plantation, it was positively correlated with atmospheric temperature while in the bamboo plantation, the most decisive factors for soil respiration rate were atmospheric temperature, relative humidity and organic matter. Soil respiration showed a pronounced seasonal fluctuation, and it was predominantly controlled by weather variables. Alongside, soil properties also played an important role in determining spatial variation of soil status in the three plantation stands. For future perspectives, studies on soil heterotrophic and autotrophic respiration are needed for a better understanding of soil respiration mechanisms in the context of a climate-change scenario. Furthermore, yearly detailed information on spatial and temporal variations of soil properties and CO_2 emission in different plantation sites and land-use systems would be necessary to construct regional carbon budgets and the current experiment and results obtained could be considered as a preliminary screening for such cumulative approach.

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Data Availability Data made available on reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Consent for Publication All authors have their consent to publish their work.

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