Forest Research
Open Access
ISSN: 2168-9776

Sundarapandian and Dar, Forest Res 2013, 3:1
DOI: 10.4172/2168-9776.1000116

Research Article | Open Access

Variation in Soil CO_2 Efflux in *Pinus Wallichiana* and *Abies Pindrow* Temperate Forests of Western Himalayas, India

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Abstract

Soil CO_2 efflux was measured by alkali absorption method from April to December 2012 in two different forest types, i.e., *Pinus wallichiana* and *Abies pindrow,* with three replicate plots in each forest type. Soil CO_2 efflux was found maximum in July and minimum in December in both the forest types. Significantly (P<0.001) greater soil CO_2 efflux was measured in *Pinus wallichiana* forest compared to *Abies pindrow* forest throughout the study period. The range of soil CO_2 efflux (mg CO_2 m^{-2} hr^{-1}) from the soil was 126-427 in *Abies pindrow* forest and 182-646 in *Pinus wallichiana* forest. Soil CO_2 efflux showed greater values in *Pinus wallichiana* forest than *Abies pindrow* forest, which could be attributed to greater tree density, tree biomass, shrub density, shrub biomass, forest floor litter and moisture. Soil CO_2 efflux also showed significant positive relationship with air temperature. In addition to that the altitudinal difference may be one of the reasons for variation in soil CO_2 efflux between the two forest types. This result also indicates that at higher altitude even a small difference in elevation (100 m) alter the functional attributes of the ecosystem.

Keywords: CO_2 efflux; *Pinus wallichiana; Abies pindrow*; Temperate forests; Western Himalayas

Introduction

Soil CO_2 efflux (SR) have received much recent attention from global change and ecosystem science communities for several reasons: (a) Soil CO_2 is the second largest carbon (C) flux in terrestrial ecosystems, and plays a critical role in global carbon cycling and (b) Soil CO_2 is a key component of biogeochemical models [1], but a large uncertainty exists in integrating respiration components into those models [2,3]. Furthermore, CO_2 efflux can vary greatly with vegetation type, soil microbial biomass, and soil chemical properties among and within sites [4,5]. Shifts in vegetation covers may profoundly affect soil CO_2 efflux and net primary production by influencing substrate quantity and quality supplied to the soil, fine root, microclimate and structure [6,7]. Approximately 70% of ecosystem respiration in temperate forests is coming from soil [8]. Globally, CO_2 efflux is estimated to be 98 ± 12 Pg C yr^{-1} or 85 Pg C yr^{-1} if agricultural areas are excluded and is increasing at a rate of 0.1 Pg C yr^{-1} [9]. Soil respiration is the main form of carbon flux from soil to atmosphere in the global carbon cycle [10]. The CO_2 efflux of forest soils has been intensively investigated during the last decade as it represents a major flux of the C cycle in forest ecosystems [11]. Soil properties, such as pH, soil depth, parent material, composition of litter fall and topography may also influence heterotrophic soil CO_2 efflux [12,13]. The two important factors for seasonal and inter-annual variability of CO_2 effluxare soil temperature and moisture [14-16]. Soil CO_2 efflux was also closely related to stand biomass and basal area of trees [17,18].

The variation of soil CO_2 efflux among forest types on different spatial scales results from interacting variables such as climatic conditions, forest productivity, litter quality, as well as physical and chemical properties of soils. Another reason for the variation of soil CO_2 efflux among different forest sites is possibly the varying contribution of heterotrophic and autotrophic respiration [19]. Underlying processes controlling Soil CO_2 efflux are not well known, for example, the coupling and decoupling of Soil CO_2 efflux with ecosystem metabolism [20]. Therefore, more data and comprehensive research on Soil CO_2 efflux from various biomes are required for assessing and predicting Rs and its responses to undergoing global changes. Quantifying the spatial and temporal patterns of soil respiration and their relations to environmental controls is essential to the C cycle in terrestrial ecosystems [21]. Soil respiration (soil surface CO_2 flux, Rs) is mainly composed of heterotrophic respiration (R_H) of microorganisms and soil animals, and autotrophic respiration (R_A) of plant roots [21,22]. The response and adaptation to environmental variables by R_H and R_A are different [23,24]. Soil CO_2 efflux represents the sum total of all soil metabolic processes in which CO_2 is produced [21,25]. The temperate forests play an important role in Indian forestry and ecological construction, where as there is no published information is available on soil respiration from temperate forests of Kashmir Himalayas. Therefore, soil CO_2 efflux of forest ecosystems and the controlling factors of CO_2 emission in these forests are not only essential to estimate C budget in forest ecosystems in western Himalaya of Jammu & Kashmir (J&K), but also important for evaluating the function of Indian temperate forest ecosystems in global C budgets.

In this study, we measured the soil CO_2 efflux in two major temperate forest types i.e., *Abies pindrow* and *Pinus wallichiana*in Western Himalaya of J&K, Pahalgam, India. The specific objectives were to: (1) compare monthly CO_2 efflux between *Abies pindrow* and *Pinus wallichiana* forest types and (2) how environmental variables alter soil CO_2 efflux between the two forest types.

Materials and Methods

Study sites

The study was conducted in the western Himalaya of Jammu &

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Received October 28, 2013; **Accepted** December 17, 2013; **Published** December 19, 2013

Citation: Sundarapandian SM, Dar JA (2013) Variation in Soil CO_2 Efflux in *Pinus Wallichiana* and *Abies Pindrow* Temperate Forests of Western Himalayas, India. Forest Res 3: 116. doi:10.4172/2168-9776.1000116

Kashmir, India (33° 20' and 34° 54'N latitudes and 73° 55' and 75° 35'E longitudes and covers an area of 15,948 km^2) between the elevations of 2210 and 2375 m.a.s.l. In these two conifer forests: *Abies pindrow* and *Pinus wallichiana*, three replicate sub-plots for each forest type were selected (Figure 1). The mean total basal area was 54.1 and 55.3 m^{-2}ha^{-1} in *Abies pindrow* and *Pinus wallichiana* respectively. The dominant shrub and herb species at both the study sites are *Vibernum grandiflorum* and *Stipa sibirica* (Table 1).

The annual precipitation during the study period was 1185.8 mm (Figure 2). However, there are differences in the daily weather conditions of Kashmir valley. This is due to high altitudinal differences. Precipitation is bimodal in nature (January-March and August-September). However, the snowfall was heavy in the month of January and February. Average Temperature reaches -8.3˚C during winter and 26˚C or above during summer [26]. January is the coldest month and June and July is the warmest month.

Measurement of total CO_2 efflux

Soil CO_2 efflux was measured by alkali absorption method [27], at two different forest types, using plastic jars, inserted 10 cm into the ground. Three replicate sub-plots in each forest type were selected for the measurement of soil CO_2 efflux. Five replicates of the plastic jars were set up in each sub-plot, and one set of three control plastic jars with airtight lids in each sub-plot. Before each plastic jar was fixed, the vegetation falling within the plastic jar was clipped at the base with the help of scissor. A 50 ml beaker containing 20 ml 0.5 N NaOH was placed in a thin wire tripod stand that holds the jar off the ground by about 2 cm. The alkali was titrated against 1N Hcl after 24 hours of absorption period to avoid diurnal variations [25,28]. The jars were placed randomly, and on each sampling date the soil moisture was measured by gravimetric method up to 10 cm soil depth. The CO_2 evolved during the experiment was calculated by following the formula of Joshi et al. [25].

Figure 1: Map showing the location of the two study sites: site I (*Pinus wallichiana*) and site II (*Abies pindrow*).

	(*Pinus wallichiana*)	(*Abies pindrow*)
Altitude (m)	2210	2375
Latitude	N 34°00'51.9	N 34°02'16.8
Longitude	E 075°18'40.6	E 075°20'35.1
Mean annual precipitation (mm)	1289	1289
Dominant tree species	*Pinus wallichiana*	*Abies pindrow*
Density (tree ha^{-1})	245 ± 16.5	232 ± 12
Tree basal area (m^{-2} ha^{-1})	55.38 ± 4.25	54.11 ± 2.63
Shrub density (No. ha^{-1})	87349 ± 2196	15547 ± 1501
Shrub Biomass (g m^{-2})	887 ± 590	330 ± 118
Forest floor litter (g m^{-2})	466.46 ± 15.39	194.13 ± 2.99
Dominant understory species	*Vibernum grandiflorum* *Stipa sibirica* *Poa bulbosa* *Fragaria nubicula*	*Vibernum grandiflorum* *Stipa sibirica* *Fragaria nubicula* *Viola odarata*
Soil C stock (Mg C ha^{-1}) 0-30 cm	55.38 ± 1.62	50.67 ± 1.20
pH	6.13 ± 0.07	6.13 ± 0.07

Table 1: Characteristics of the *Pinus wallichiana* and *Abies pindrow* temperate forest in western Himalayas, India.

$MgCO_2$ = VxNx22,

Where V represents titration of the blank minus the sample titration and N is the normal acid value.

In the month of October, 15 soil cores up to 30 cm depth were collected randomly in each sub-plot and mixed together to make a composite soil sample. Five representative soil samples from each sub-plot were taken into the laboratory for further analysis. Soil organic carbon (SOC) was estimated by following the formula of Pearson et al. [29].

Statistical analysis

The variation in soil CO_2 efflux in two different forest types (*Pinus wallichiana* and *Abies pindrow*) was examined with student't' test. The relationship between soil CO_2 efflux with tree density, shrub density, shrub biomass, forest floor litter, and SOC was examined with linear and regression analyses.

Results

Total soil CO_2 efflux (mg CO_2 $m^{-2}hr^{-1}$) showed a similar temporal pattern in both the two forest types, the values being highest during the month of July and lowest during the December month (Figure 3). The soil CO_2 efflux in the month of January, February and March has not been measured due to complete snow cover. The *Pinus wallichiana* forest type showed a higher rate of CO_2 efflux throughout the study period as compared to *Abies pindrow* forest type. The mean CO_2 efflux

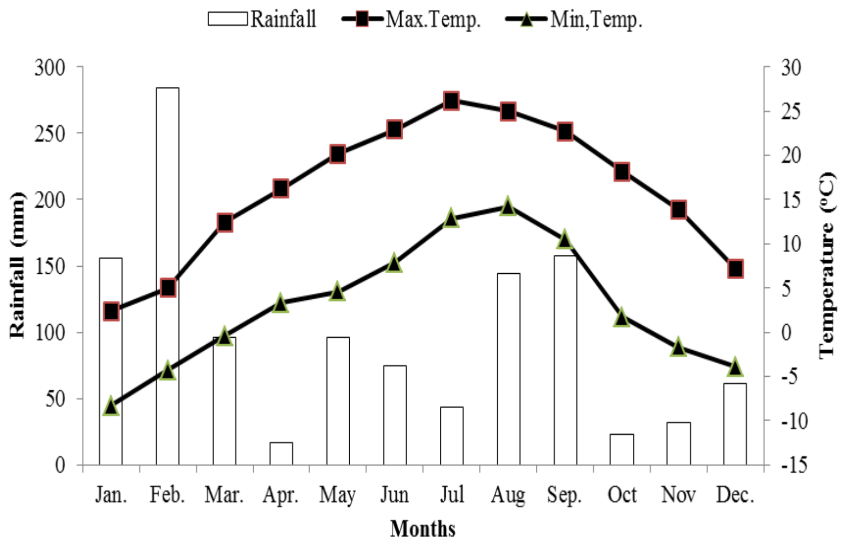

Figure 2: Mean monthly maximum and minimum temperatures and rainfall pattern of the study areas in two temperate forests of western Himalayas, India.

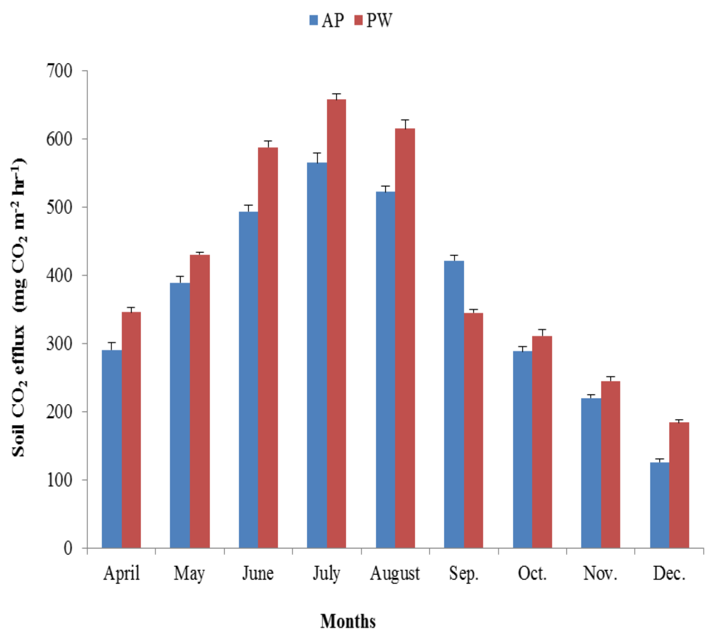

Figure 3: Mean monthly Soil CO_2 efflux in two different temperate forest types (*Abies pindrow* & *Pinus wallichiana*) in western Himalayas, India.

(mg CO_2 $m^{-2}hr^{-1}$) values ranged from 126-427 in *Abies pindrow* forest and 182-646 in *Pinus wallichiana* forest.

The CO_2 efflux showed positive correlation with tree density, shrub density, shrub biomass, forest floor litter, soil organic carbon (SOC) and air temperature (Figure 4a and 4b). However, tree basal area, herb biomass, herb density, rainfall and soil pH showed very weak correlation with soil CO_2 efflux.

Discussion

In the present study soil CO_2 efflux peaked during the warm summer month's July-August and decreased during the cold winter, December. A similar temporal variation in soil respiration was observed in several temperate forest ecosystems [3,30-33]. In the present study, as the warmer months approached with frequent precipitation, the micro-organisms inhabiting the soil became more active causing an enhanced CO_2 efflux rates as observed by Pandey et al. [32]. Similar trend of significant positive correlation of soil CO_2 with temperature has been reported by several investigators on temperate forest ecosystems [34,35]. Minimum rate of CO_2 efflux from both forest types was recorded in winter months as a result of decreased microbial populations during this period as reported by Pandey et al. [32]. The low solar radiation in winter months may be one of the reasons for lower CO_2 efflux rate in winter months [36]. The estimated CO_2 efflux ranged from 126-427 in *Abies pindrow* forest and 182-646 in *Pinus wallichiana* forest during the present studyis well within the range reported in various temperate forests [3,34,37].

Vegetation may alter soil CO_2 efflux rate by influencing soil micro-climate and structure, the quantity and quality of detritus supplied to the soil, and overall rate of root respiration [7,38,39]. In the present study, the *Pinus wallichiana* forest type showed significantly greater ($P<0.01$) rate of CO_2 efflux throughout the study period as compared to *Abies pindrow* forest type. Similarly the differences in vegetation-related controls on CO_2 efflux have been evaluated for different places for different ecosystems [6,7,36,40,41]. Greater CO_2 efflux in *Pinus wallichiana* site could be attributed to greater tree density, shrub density, shrub biomass, forest floor litter and SOC.

Numerous studies have shown that climatic factors, particularly temperature and precipitation are the major determinants of CO_2 efflux at global, regional and local scales [42]. Several studies stated that air temperature have negative relationship with CO_2 efflux [43,44]. In the present study soil temperature showed significant positive correlation with CO_2 efflux. It is generally acceptable that temperature is a key abiotic variable that controls on soil CO_2 efflux. Similar results on the positive correlation between soil CO_2 efflux and temperature have been observed by Lloyd and Taylor [45] and Lin et al. [46]. Generally in cold temperate forests, raising air temperature might be creating favourable environment for microbial growth as well as herbaceous community

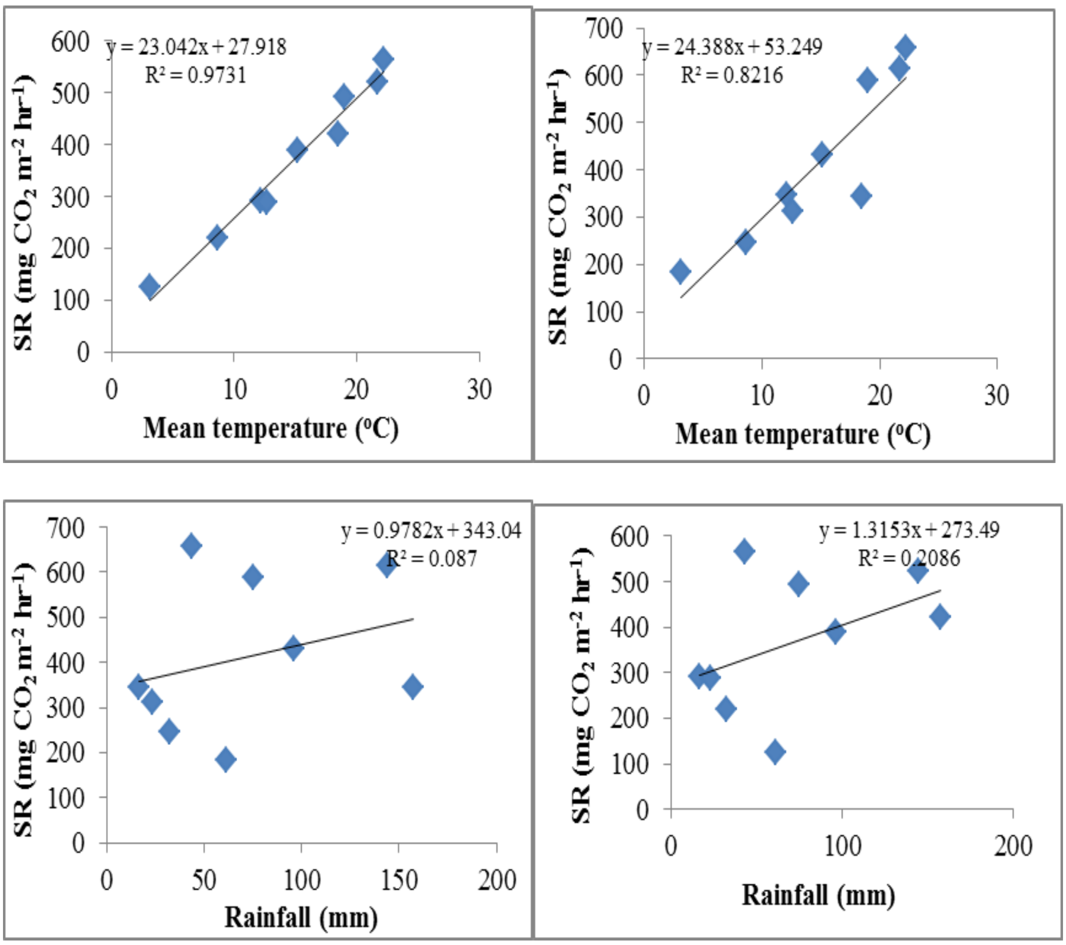

Figure 4a: Relationship between mean soil CO_2 efflux and atmospheric parameters (rainfall and mean temperatures) in temperate forests of western Himalayas, India.

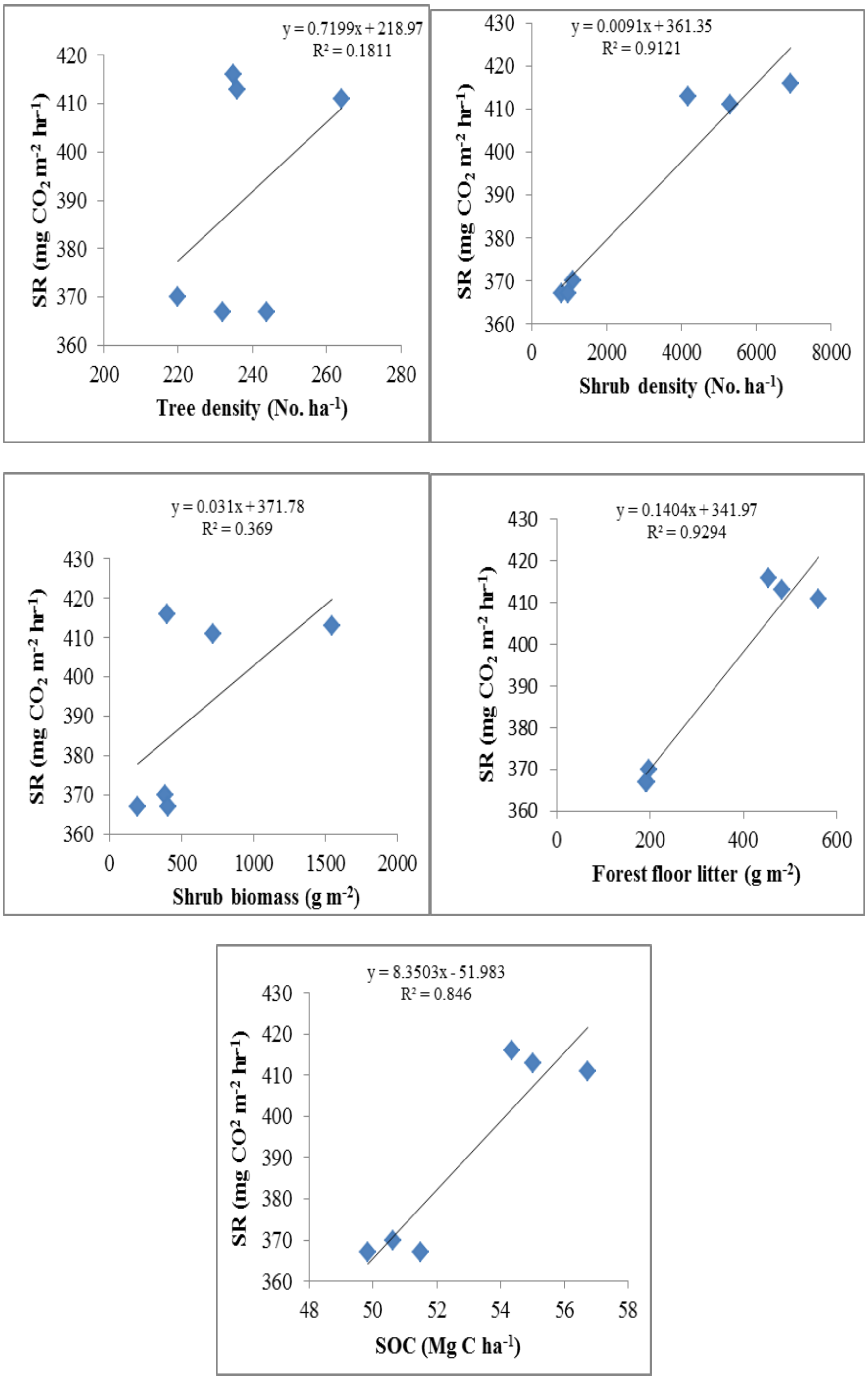

Figure 4b: Relationship between mean soil CO_2 efflux with vegetation and soil parameters in temperate forests of western Himalaya, India.

establishment which is reason for increase in CO_2 efflux during higher temperature period. Rainfall has also showed weak correlation with soil CO_2 efflux which is in accordance with [3,39,47,48].

Carbon stocks in soil and forest floor litter significantly contribute to ecosystem CO_2 efflux through manipulating autotrophic and heterotrophic respiration [33,49,50], but these variables are less considered than soil moisture and soil temperature in calculating soil respiration. Zhou et al. [33] stated that combined carbon stock in litter and top soil explain 48% of spatial variation of CO_2 efflux in temperate forests. In the present study various parameters such as tree density, shrub density, shrub biomass, forest floor litter and SOC have showed positive correlation with CO_2 efflux. The similar results have been shown by other studies [3,33] in temperate forests. The present study revealed that vegetation types and its associated micro-climate determine the rate of soil CO_2 efflux.

Acknowledgement

We thankfully acknowledge the financial support provided by UGC, Government of India for its fellowship. Forest Department of Anantnag & Lidder in

J&K for permission and Islamaia College of Science and Commerce for laboratory facilities. We appreciate the contribution of anonymous reviewer(s) and the editor for valuable comments on the manuscript.

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