Variation in Soil CO₂ Efflux in Pinus Wallichiana and Abies Pindrow Temperate Forests of Western Himalayas, India

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Abstract
Soil CO₂ 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 CO₂ efflux was found maximum in July and minimum in December in both the forest types. Significantly (P<0.001) greater soil CO₂ efflux was measured in Pinus wallichiana forest compared to Abies pindrow forest throughout the study period. The range of soil CO₂ efflux (mg CO₂ m⁻² hr⁻¹) from the soil was 126-427 in Abies pindrow forest and 182-646 in Pinus wallichiana forest. Soil CO₂ 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 CO₂ 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 CO₂ efflux between the two forest types. This result also indicates that at higher altitude even a small difference in elevation (100 m) after the functional attributes of the ecosystem.

Keywords: CO₂ efflux; Pinus wallichiana; Abies pindrow; Temperate forests; Western Himalayas

Introduction
Soil CO₂ efflux (SR) have received much recent attention from global change and ecosystem science communities for several reasons: (a) Soil CO₂ is the second largest carbon (C) flux in terrestrial ecosystems, and plays a critical role in global carbon cycling and (b) Soil CO₂ is a key component of biogeochemical models [1], but a large uncertainty exists in integrating respiration components into those models [2,3]. Furthermore, CO₂ 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 CO₂ 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, CO₂ 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 CO₂ 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 CO₂ efflux [12,13]. The two important factors for seasonal and inter-annual variability of CO₂ effluxare soil temperature and moisture [14-16]. Soil CO₂ efflux was also closely related to stand biomass and basal area of trees [17,18].

The variation of soil CO₂ 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 CO₂ efflux among different forest sites is possibly the varying contribution of heterotrophic and autotrophic respiration [19]. Underlying processes controlling Soil CO₂ efflux are not well known, for example, the coupling and decoupling of Soil CO₂ efflux with ecosystem metabolism [20]. Therefore, more data and comprehensive research on Soil CO₂ 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 CO₂ flux, Rs) is mainly composed of heterotrophic respiration (RH) of microorganisms and soil animals, and autotrophic respiration (RA) of plant roots [21,22]. The response and adaptation to environmental variables by RH and RA are different [23,24]. Soil CO₂ efflux represents the sum total of all soil metabolic processes in which CO₂ 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 CO₂ efflux of forest ecosystems and the controlling factors of CO₂ 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 CO₂ efflux in two major temperate forest types i.e., Abies pindrow and Pinus wallichianan Western Himalaya of J&K, Pahalgam, India. The specific objectives were to: (1) compare monthly CO₂ efflux between Abies pindrow and Pinus wallichiana forest types and (2) how environmental variables alter soil CO₂ efflux between the two forest types.

Materials and Methods

Study sites
The study was conducted in the western Himalaya of Jammu &
Kashmir, India (33° 20’ and 34° 54’N latitudes and 73° 55’ and 75° 35’E longitudes and covers an area of 15,948 km²) 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 m²ha⁻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 CO₂ efflux**

Soil CO₂ 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 CO₂ 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 CO₂ evolved during the experiment was calculated by following the formula of Joshi et al. [25].

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

<table>
<thead>
<tr>
<th></th>
<th>(Pinus wallichiana)</th>
<th>(Abies pindrow)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Altitude (m)</strong></td>
<td>2210</td>
<td>2375</td>
</tr>
<tr>
<td><strong>Latude</strong></td>
<td>N 34°00’51.9</td>
<td>N 34°02’16.8</td>
</tr>
<tr>
<td><strong>Longitude</strong></td>
<td>E 075°18’40.6</td>
<td>E 075°20’35.1</td>
</tr>
<tr>
<td><strong>Mean annual precipitation (mm)</strong></td>
<td>1289</td>
<td>1289</td>
</tr>
<tr>
<td><strong>Dominant tree species</strong></td>
<td>Pinus wallichiana</td>
<td>Abies pindrow</td>
</tr>
<tr>
<td><strong>Density (tree ha⁻¹)</strong></td>
<td>245 ± 16.5</td>
<td>232 ± 12</td>
</tr>
<tr>
<td><strong>Tree basal area (m² ha⁻¹)</strong></td>
<td>55.38 ± 4.25</td>
<td>54.11 ± 2.63</td>
</tr>
<tr>
<td><strong>Shrub density (No. ha⁻¹)</strong></td>
<td>87349 ± 2196</td>
<td>15547 ± 1501</td>
</tr>
<tr>
<td><strong>Shrub Biomass (g m⁻²)</strong></td>
<td>887 ± 590</td>
<td>330 ± 118</td>
</tr>
<tr>
<td><strong>Forest floor litter (g m⁻²)</strong></td>
<td>466.46 ± 15.39</td>
<td>194.13 ± 2.99</td>
</tr>
<tr>
<td><strong>Dominant understory species</strong></td>
<td>Vibernum grandiflorum</td>
<td>Stipa sibirica</td>
</tr>
<tr>
<td></td>
<td>Stipa sibirica</td>
<td>Poa bulbosa</td>
</tr>
<tr>
<td></td>
<td>Fragaria rubicula</td>
<td>Viola odorata</td>
</tr>
<tr>
<td><strong>Soil C stock (Mg C ha⁻¹)</strong></td>
<td>55.38 ± 1.62</td>
<td>50.67 ± 1.20</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>6.13 ± 0.07</td>
<td>6.13 ± 0.07</td>
</tr>
</tbody>
</table>

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**Figure 1:** Map showing the location of the two study sites: site I (Pinus wallichiana) and site II (Abies pindrow).
$\text{MgCO}_2 = V_xN_x22,$

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’s 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
(mg CO₂ m⁻² h⁻¹) values ranged from 126-427 in Abies pindrow forest and 182-646 in Pinus wallichiana forest.

The CO₂ 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 CO₂ efflux.

Discussion

In the present study soil CO₂ 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 CO₂ efflux rates as observed by Pandey et al. [32]. Similar trend of significant positive correlation of soil CO₂ with temperature has been reported by several investigators on temperate forest ecosystems [34,35]. Minimum rate of CO₂ 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 CO₂ efflux rate in winter months [36]. The estimated CO₂ efflux ranged from 126-427 in Abies pindrow forest and 182-646 in Pinus wallichiana forest during the present study is well within the range reported in various temperate forests [3,34,37].

Vegetation may alter soil CO₂ efflux rate by influencing soil microclimate 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 CO₂ efflux throughout the study period as compared to Abies pindrow forest type. Similarly the differences in vegetation-related controls on CO₂ efflux have been evaluated for different places for different ecosystems [6,7,36,40,41]. Greater CO₂ 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 CO₂ efflux at global, regional and local scales [42]. Several studies stated that air temperature have negative relationship with CO₂ efflux [43,44]. In the present study soil temperature showed significant positive correlation with CO₂ efflux. It is generally acceptable that temperature is a key abiotic variable that controls on soil CO₂ efflux. Similar results on the positive correlation between soil CO₂ 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 CO₂ efflux and atmospheric parameters (rainfall and mean temperatures) in temperate forests of western Himalayas, 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**

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26. IMD (Indian Meteorological Department, Srinagar) Temperature and rainfall.


