Tree Species Influence Soil Respiration in a Temperate Forest of Uttrakhand Himalaya, India

Article *in* Journal of Sustainable Forestry · September 2020

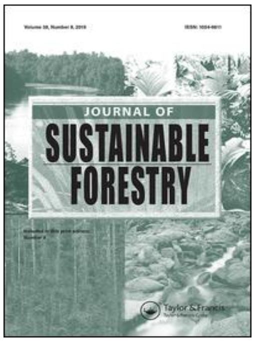
DOI: 10.1080/10549811.2020.1822873

3 authors:

Monika Rawat
Indian Council of Forestry Research and Education (ICFRE)

Kusum Arunachalam

Ayyanadar Arunachalam
Indian Council of Agricultural Research



Journal of Sustainable Forestry

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/wjsf20

Tree Species Influence Soil Respiration in a Temperate Forest of Uttrakhand Himalaya, India

Monika Rawat , Kusum Arunachalam & Ayyandar Arunachalam

To cite this article: Monika Rawat , Kusum Arunachalam & Ayyandar Arunachalam (2020): Tree Species Influence Soil Respiration in a Temperate Forest of Uttrakhand Himalaya, India, Journal of Sustainable Forestry

To link to this article: https://doi.org/10.1080/10549811.2020.1822873

Published online: 20 Sep 2020.

JOURNAL OF SUSTAINABLE FORESTRY
https://doi.org/10.1080/10549811.2020.1822873

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

Check for updates

Tree Species Influence Soil Respiration in a Temperate Forest of Uttrakhand Himalaya, India

Monika Rawat[a], Kusum Arunachalam[a], and Ayyandar Arunachalam[b]

[a]School of Environment and Natural Resources, Doon University, Dehradun, India; [b]Indian Council of Agricultural Research, Krishi Bhawan, New Delhi, India

ABSTRACT

We investigated the influence of dominant tree species and seasonal variation of the soil respiration rates in the temperate forest of the Indian Himalayan region. Ten dominant tree species based on the ecological parameters were selected for the study; seven were evergreen *(Abies pindrow, Cedrus deodara, Cupressus torulosa, Eunonymous pendulous, Pinus wallichiana, Quercus leucotrichophora*, and *Rhododenderon arboreum)* and three were deciduous (*Aesculus indica, Pyrus paschia*, and *Toona ciliata*). Soil respiration was highest under the canopy of *Eunonymous pendulous* i.e. 25.33 µmol CO_2 m^{-2} s^{-1} and lowest under *Rhododenderon arboreum* i.e. 0.10 µmol CO_2 m^{-2} s^{-1} tree species. The trend of canopy influence of tree species on soil respiration followed the order of *Eunonymous pendulous* > *Aesculus indica* >*Abies pindrow*> *Pyrus paschia* >*Cedrus deodara* >*Pinus wallichiana* >*Cupressus torulosa* >*Toona ciliata* > *Quercus leucotrichophora* > *Rhododenderon arboreum*. Seasonally, soil respiration was higher during the rainy season when litter decomposition is at its peak and lowers in winter. There is a positive correlation of soil respiration with soil physicochemical properties i.e. soil pH, soil moisture, total carbon, microbial biomass C and N. However, negative correlations were detected between soil respiration and microbial biomass P, and total P. Overall results clearly define the differential influence of trees species growing in a given forest on the soil CO_2 efflux in a temperate forest ecosystem, thus warranting further research on the functional trait-based analysis on the overall biomass dynamics on the forest floor *vis-à-vis* CO_2 and nutrient flux in the topsoil.

KEYWORDS
Soil respiration; microbial biomass; temperate forest; tree species; organic carbon

Introduction

Soil respiration is defined as the outcome of respiration by autotrophic respiration, i.e. plant roots and heterotrophic respiration, i.e. soil organisms (Li et al., 2006; Singh & Parida, 2019). Both autotrophic and heterotrophic respirations are influenced by temperature and precipitation (Prasad & Baishya, 2019; Qi & Xu, 2001). Soil respiration is a significant component of the terrestrial carbon cycle (Michelsen et al., 2004; Schlesinger & Andrews, 2000). Several studies investigated the impact of seasonal variation on soil respiration (Dar et al., 2015; Jina et al., 2008; Joshi et al., 1991; Ruehr et al., 2010; Ruehr & Buchmann, 2010; Singh & Parida, 2019; Vincent et al., 2006; Yohannes et al., 2011). However, limited understanding persists on the influence of the tree species on soil respiration (Bréchet

CONTACT Monika Rawat monikapft@gmail.com School of Environment and Natural Resources, Doon University, Dehradun 248001, India

et al., 2009; Chen & Chen, 2019; Fu et al., 2013; Liu et al., 2017; James W. Raich & Tufekciogul, 2000; Vesterdal et al., 2012), as the ecological processes, such as above-belowground litter production and root respiration vis-à-vis soil microbial activity, are regulated by the belowground ecology of the tree species (J et al., 2003; Han et al., 2015; Li et al., 2006; M. Liu et al., 2017; Prasad & Baishya, 2019; Singh & Parida, 2019).

Besides the influence of seasonal activity and tree species effect on soil respiration. Soil respiration rates have a significant and positive correlation with soil physicochemical and microbial property. Many studies provided the evidence that soil respiration is positively associated with soil organic carbon (Fan et al., 2015), soil pH (Chen et al., 2016), soil moisture (Li et al., 2006; Mohanty & Panda, 2011; Prasad & Baishya, 2019), and soil microbial biomass C and N (Li et al., 2006; Michelsen et al., 2004). Human disturbances and climate change affect the soil respiration rate therefore for sustainable carbon management in forest ecosystems it is essential to understand the influence of tree species on soil CO_2 respiration.

The Himalayas are known for bioresource richness, species dynamics, and in global carbon storage (Dar & Sundarapandian, 2014, 2016; Rawat et al., 2019). In particular, the functioning of the high Himalayan forests is of great importance in the era of climate change and ecological niche of species due to the influence of the former on the latter. So, the forest managers need scientific validation of species influence on soil carbon that directly and/or indirectly facilitates the forest regeneration *per se*. The present study was an attempt to understand the flux of soil respiration under the canopy of a few dominant tree species of a temperate forest to understand *in situ* relationships between soil respiration and other soil parameters. To test the hypothesis is there any influence of tree species on soil respiration rate in the temperate forest ecosystem.

Materials and methods

Study area

The present study was conducted in Mussorie forest division (30° 28′02.6” N latitude and 78° 05′ 47.9” E longitude) which consists of a diversity of temperate forest species. The selected site is located at 2200 m asl. Soils of the region are leptosols, regosols, and cambisols developed mostly on dolomite (Raina & Gupta, 2009). The composition of the forest was analyzed using nested quadrat method. Trees were analyzed by 10 m x 10 m quadrats as proposed by (Curtis & McIntosh, 1950). Each of the 20 selected plots was characterized by analyzing soil samples. Three soil samples were randomly collected from each of the 20 plots, making a total of 60 soil samples per season, or 180 samples for the three seasons of the study. These soil samples were collected from 0 to 30 cm depth at randomly selected points under the canopy of the selected tree species. Evergreen tree species selected for the study were – *Abies pindrow* Spach Ham, *Cedrus deodara* Loud, *Cupressus torulosa* D. Don, *Pinus wallichiana* Jackson, *Euonymus pendulous* Wall, *Quercus leucotrichophora* A.Comm and *Rhododendron arboretum* Smith and deciduous ones were *Aesculus indica* Colebr, *Pyrus pashia* Buch. Hemex D. Don and *Toona ciliata* R. Sampling were done in three-season summer (March–June), rainy (July–September), and winter (October–February) in the 2014–2016 yr. The mean values of the soil physicochemical and microbial biomass C, N, and P are presented in Table 1. Overall, the soil bulk density was 1.33 g cm^{-3}, soil pH was 6,

Table 1. Soil physicochemical and biological properties studied in the temperate forest.

Soil properties	Mean ± SE
Soil texture	
Sand (%)	63
Silt (%)	17
Clay (%)	20
Bulk density (g cm^{-3})	1.33
Soil moisture content (%)	28.31 ± 0.95
Soil pH	6.55 ± 0.05
Soil organic C (%)	2.5 ± 0.03
Total C (%)	10.81 ± 0.48
Available N (µg/g)	53.17 ± 3.94
Total N (%)	0.89 ± 0.05
Available P (µg/g)	185.84 ± 17.25
Total P (%)	1.12 ± 0.37
Potassium (µg/g)	242.61 ± 21.63
Microbial biomass carbon (µg/g)	1694.45 ± 94.05
Microbial biomass nitrogen (µg/g)	55.31 ± 3.20
Microbial biomass phosphorous (µg/g)	7.89 ± 0.92

soil moisture content 28.31%, and organic carbon 2.5% in the studied forest. And, soil microbial biomass of carbon, nitrogen, and phosphorous was 1694.45, 55.31, and 7.89 µg/g, respectively.

Soil properties measurements

Soil samples were collected from two different depths (0–15 and 15–30 cm) for assessing the physicochemical and biological properties of soil under the canopy of the chosen dominant tree species. The composite soil sample of each of the species was divided equally into two parts; one part was immediately (within 24 h) sieved (2 mm mesh screen) and analyzed for pH (digital pH meter), moisture content (gravimetric method), ammonium-N (Kjeldahl method) and available P (molybdenum blue method) with UV-VIS spectrophotometer (Thermo, Evolution 201). The other part of the soil was sieved through a 2 mm mesh screen, air-dried under laboratory conditions, and was determined for texture (Boyoucous hydrometric method). The remaining air-dried soil samples were again sieved through a 0.5 mm mesh screen and used for the analysis of soil organic carbon, potassium, total carbon, nitrogen, and phosphorous standard procedures were followed for soil analysis (Anderson & Ingram, 1994). Soil organic carbon was measured with Walkley and Black (1934). Soil total carbon and nitrogen with CHNS (EURO EA 3000) elemental analyzer, total phosphorous with acid digestion method, and potassium with a flame photometer (Systonics, 128).

Microbial biomass carbon, nitrogen and phosphorous measurements

Microbial C and microbial N were estimated by chloroform fumigation-extraction method (Anderson & Ingram, 1994) using two sets of treatment (chloroform fumigated and unfumigated) and extracted in 0.5 N K_2SO_4 and simultaneously digested and titrated against ferrous ammonium sulfate using 1,10 phenanthroline monohydrate as the indicator and N/140 HCl using the boric acid indicator, respectively. Microbial P was estimated by chloroform fumigation extraction technique (Anderson & Ingram, 1994) using 0.5 N $NaHCO_3$ (Brookes et al., 1984). In all cases, the values of unfumigated samples were subtracted from fumigated one to get the values for microbial C, N, and P.

Soil respiration measurements

Closed chamber method automated LI-COR 8100 soil CO_2 flux system (LICOR, USA) was used for measuring soil CO_2 efflux rates (μmol CO_2 m^{-2} s^{-1}) under the canopy of dominant tree species of temperate forest. In this method, a small portion of air is circulated from a chamber to an infrared gas analyzer (IRGA) and then sent back to the chamber. Measurements were taken with a 20-cm survey chamber, which was connected to the LI-8100 analyzer. Soil collars were inserted into the soil 10 cm from the ground surface. To measure the variability of soil CO_2 efflux under each dominant tree species, three random locations were selected in the plot (Mishra et al., 2020; Prasad & Baishya, 2019). The rate of CO_2 efflux reading was logged at regular interval and recorded in the data logger (LI-1400, LI-COR, Lincoln, NE, USA). Soil CO_2 efflux was measured under the dominant tree species in three different seasons from 6:00 to 18:00 h.

Data analysis

ANOVA was used to test the significant differences between soil respiration, species, and season (Table 2). Pearson correlation analyses were used to examine the relationship between soil respiration and soil properties. SPSS 23 and R Studio analytical tools were used for analyses.

Results

Soil respiration under the tree canopy

Estimations of soil respiration under the canopy of dominant tree species of the temperate forest ecosystem ranged from 0.10 to 25.33 μmol CO_2 m^{-2} s^{-1}. Across species, lowest soil respiration rate was recorded for *Rhododenderon arboreum* (0.10 μmol CO_2 m^{-2} s^{-1}) and highest under the canopy of *Eunonymous pendulus* (25.33 μmol CO_2 m^{-2} s^{-1}) (Figure 1).

Seasonal variation in soil respiration

Soil respiration showed significant seasonal variation under the canopy of dominant tree species (Figure 2). For instance, the rate of soil respiration was maximum during the rainy season under the canopy of all species, except *Quercus leucotrichophora* that registered

Table 2. Two-way ANOVA effect of species, season, and their interaction on soil respiration.

Source	df	F	Significance value
Species	9	28.20	0.000*
Season	2	174.49	0.000*
Species * Season	18	14.29	0.000*

*Significance level p>0.05 level.

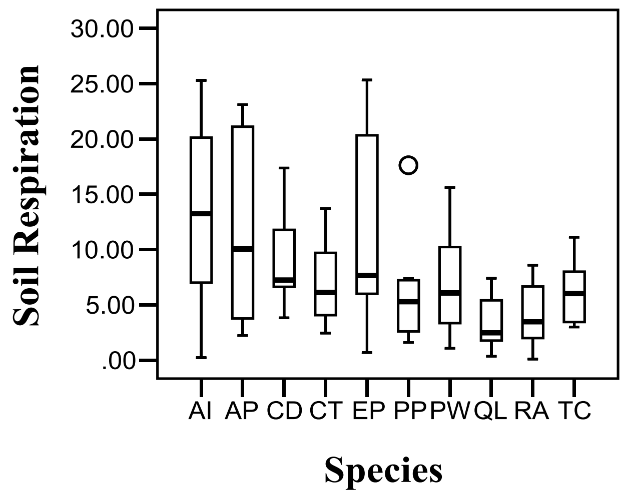


Figure 1. Soil respiration (μmol CO_2 m^{-2} s^{-1}) variation among dominant tree species of temperate forest. *Aesculus indica* (AI), *Abies pindrow* (AP), *Cedrus deodara* (CD), *Cupressus torulosa* (CT), *Euonymus pendulous* (EP), *Pyrus pashia* (PP), *Pinus wallichiana* (PW), *Quercus leucotrichophora* (QL), *Rhododendron arboretum* (RA) and *Toona ciliata* (TC)

higher rate during winter and *Cupressus torulosa* in summer. Winter (W), Summer (S), and Rainy (R) seasonal soil respiration variation among dominant tree species as follows: *Aesculus indica* (Mean; W: 3.95, S: 13.44, R: 20.54 μmol CO_2 m^{-2} s^{-1}), *Abies pindrow* (Mean; W: 3.63, S: 11.24 and R: 21.44 μmol CO_2 m^{-2} s^{-1}), *Eunonymous pendulous* (Mean; W: 3.51, S: 7.06, R: 22.42 μmol CO_2 m^{-2} s^{-1}), *Pyrus paschia* (Mean; W: 3.66, S: 4.23, R: 10.41 μmol CO_2 m^{-2} s^{-1}), *Pinus wallichaiana* (Mean; W: 3.90, S: 4.84, R: 12.87 μmol CO_2 m^{-2} s^{-1}) and recorded the seasonal trend in the descending order of rainy > summer > winter.

Influence of soil properties on soil respiration

In the present study, the rate of soil respiration recorded significant positive correlations with other soil properties such as pH, moisture, total carbon, and microbial biomass C and N. Soil respiration, however, registered negative correlations with microbial biomass P and soil total P (Figure 3).

Discussion

Soil respiration under the tree canopy

Our study reported contrasting results for evergreen (*Abies pindrow: 23.11* μmol CO_2 m^{-2} s^{-1}, *Pinus wallichaiana: 15.62* μmol CO_2 m^{-2} s^{-1}, *Cupressus torulosa: 13.72* μmol CO_2 m^{-2} s^{-1}, *Cedrus deodara: 17.37* μmol CO_2 m^{-2} s^{-1}, *Quercus leucotrichophora: 7.41* μmol CO_2 m^{-2} s^{-1}, *Rhododenderon arboreum: 8.59* μmol CO_2 m^{-2} s^{-1} and *Eunonymous pendulous*: 25.33 μmol CO_2 m^{-2} s^{-1}) and deciduous tree species (*Pyrus paschia:17.62* μmol CO_2 m^{-2} s^{-1}, *Aesculus indica* μmol CO_2 m^{-2} s^{-1}*: 25.29* and *Toona ciliata: 11.12* μmol CO_2 m^{-2} s^{-1})

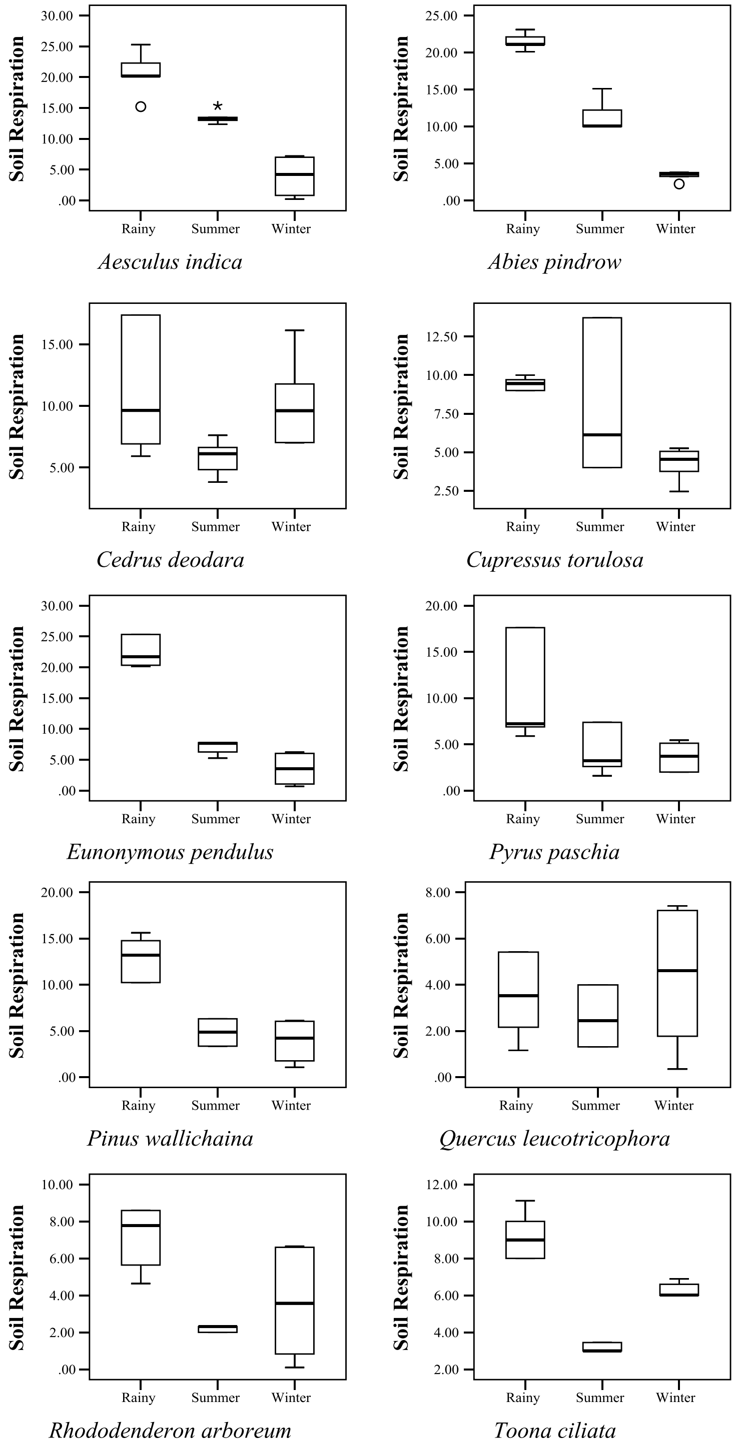


Figure 2. Box plots showing seasonal variation in soil respiration (μmol CO_2 m^{-2} s^{-1}) in dominant tree species of temperate forest.

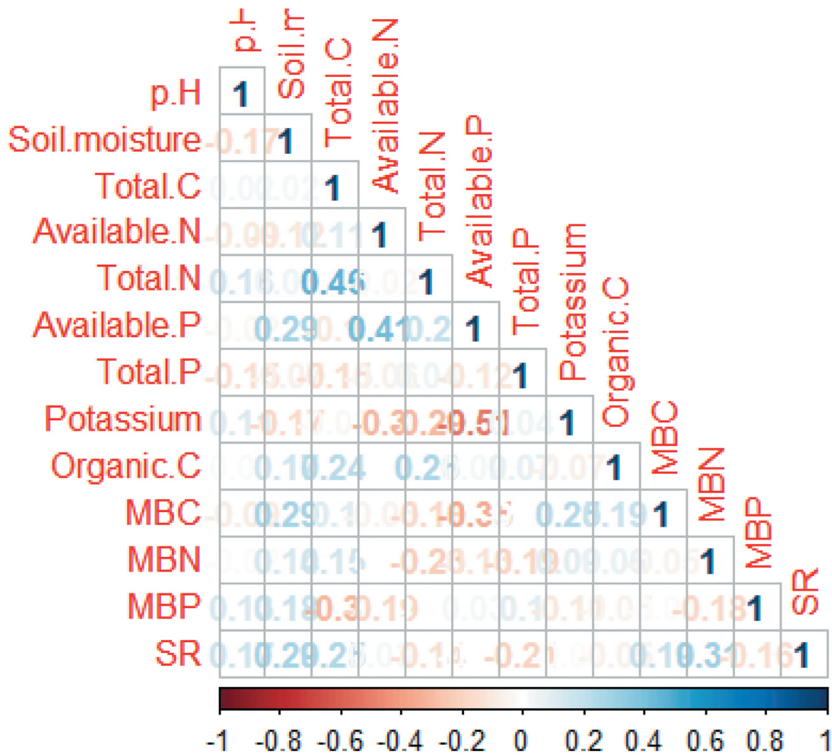


Figure 3. Correlation between soil respiration and soil properties of the temperate forest ecosystem. **Positive correlations** are displayed in blue and **negative correlations** in red color numbers. (Microbial biomass carbon, MBC, Microbial biomass nitrogen, MBN, Microbial biomass phosphorous, MBP and Soil respiration, SR).

(Figure 1). This might be due to soil respiration varies with plant canopy cover under different vegetation. Plant canopy cover affects the microclimate (Aalto et al., 2013; Fu et al., 2013; Liu et al., 2014; Tanaka & Hashimoto, 2006); therefore, high soil respiration was under large canopy for regulating the micro-climatic conditions and builds favorable rhizospheric conditions for microbes and low soil respiration under the small/narrow canopy. In this study, soil respiration was lower under *Rhododenderon arboreum*, whilst greater carbon-dioxide evolution was under *Eunonymous pendulous*, presumably due to variability in litter composition and biomass production suggested by (Han et al., 2015; Hanson et al., 2003; Kara et al., 2008). This trend conforms with the contention of tree species influence on soil respiration by (Han et al., 2015; Raich & Schlesinger, 1992).

Seasonal variation in soil respiration

Our study reported seasonal variation in soil respiration which is consistent with other studies (Dar et al., 2015; Jina et al., 2008; Singh & Parida, 2019; Vincent et al., 2006) in the forest ecosystem. For instance, soil respiration was maximum during rainy and lowest during winter (Figure 2) due to greater activity of microbes during monsoon than in the winter, when the organic matter decomposition has been reported to be low due to low temperature (Arunachalam et al., 1998). Besides, the soil water availability also increases during the rainy season which promotes rapid mineralization *per se* (Joshi, 1995; Singh & Parida, 2019).

Under the canopy of most of the tree species studied, there were high soil respiration rates, particularly during the rainy season due to favorable micro-climatic conditions in the forest floor that promotes enhanced root respiration and microbial activities (Fu et al., 2013; Yang et al., 2018). And the possible reason for low soil CO_2 efflux during winter might be the result of low temperatures and high light intensity that reduces the microbial growth and therefore manifest slowly to zero decay.

Furthermore, soil respiration was recorded to be lower under the canopy of *Cedrus deodara, Rhododendron arboreum*, and *Toona ciliata* summer when species like *Cupressus torulosa* had its peak. Although the reasons for such dynamic flux in the soil respiration rates results as influenced by different species with variety canopy patterns are not known immediately, this sets the stage for further research, in particular on the foliage-based functional traits of the tree species and its dynamics on the forest floor vis-à-vis below-ground dynamics and CO_2 flux. Nonetheless, seasonality in soil variables across seasons may have a significant effect on the carbon and nutrient balance in the region (Singh & Parida, 2019). With specific reference to the Himalayan region, the recorded rate of CO_2 evolution from the soil could be compared with the seasonality in the observations of Joshi (1995) while working in a grassland ecosystem; monsoon (101–159 mg CO_2m^{-2} h^{-1}) and winter and summer (35–101 mg CO_2m^{-2} h^{-1}), and also that of Dar & Sundarapandian (2014) for *Abies pindrow* dominant forest (126–427 mg CO_2 m^{-2} hr^{-1}) and *Pinus wallichiana* forest (182–646 mg CO_2 m^{-2} hr^{-1}) (Dar & Sundarapandian, 2014). These comparative observations further indicate the species influence on the seasonality in soil respiration rates.

Influence of soil properties on soil respiration

Soil respiration rates (Figure 3) had significant positive correlations with soil properties, i.e. pH, moisture, total carbon, microbial biomass C and N and this conforms with the findings for soil pH (Chen et al., 2016; Fan et al., 2015), for soil moisture by (Li et al., 2006; Mohanty & Panda, 2011; Prasad & Baishya, 2019), for microbial biomass C and N (Li et al., 2006; Michelsen et al., 2004) in different land-use systems. In contrast to the observations of Luo et al. (2012) and Dar et al. (2015), we found no correlation with organic carbon, however. This again indicates the variability in the quality of litter traits of different tree species to be affecting the microbial activities both on the forest floor and in the topsoil. Our results also identified that total P and soil microbial biomass P has a negative association with soil respiration. This is evident, as solubilization of phosphorus in the soil too is related to the specificities in the microbial activity (Brookes et al., 1984) as also enabled by the residue recycling process enabled by the composition of forest vegetation *per se* (Chandra et al., 2016; Fu et al., 2013). Overall, the present results clearly define the differential influence of tree species growing in a given forest on the soil CO_2 efflux in a temperate forest ecosystem, thus warranting further research on the functional trait-based analysis on the overall biomass dynamics on the forest floor *vis-à-vis* CO_2 and nutrient flux in the topsoil.

Acknowledgments

We gratefully acknowledge the Department of Science and Technology (DST), Government of India, for providing financial support through the INSPIRE Fellowship to MR. Laboratory facilities at Doon University were used for analytical work.

Funding

This work was supported by the Department of Science and Technology India [Inspire fellowship].

Author contribution

MR, KA and AA conceptualized, designed, and developed the questionnaire; MR collected the data and analyzed the data. KA and AA read and modified the draft manuscript.

References

Aalto, J., Roux, P. C. L., & Luoto, M. (2013). Vegetation mediates soil temperature and moisture in arctic-alpine environments. *Arctic, Antarctic, and Alpine Research*, *45*(4), 429–439. https://doi.org/10.1657/1938-4246-45.4.429

Anderson, M., & Ingram, J. (1994). Tropical soil biology and fertility: A handbook of methods. *Soil Science*, *157*(4), 265. https://doi.org/10.2307/2261129

Arunachalam, A., Maithani, K., Pandey, H. N., & Tripathi, R. S. (1998). Leaf litter decomposition and nutrient mineralization patterns in regrowing stands of a humid subtropical forest after tree cutting. *Forest Ecology and Management*, *109*(1-3), 151–161 doi:10.1016/S0378-1127(98)00240-0

Bréchet, L., Ponton, S., Roy, J., Freycon, V., Coûteaux, -M.-M., Bonal, D., & Epron, D. (2009). Do tree species characteristics influence soil respiration in tropical forests? A test based on 16 tree species planted in monospecific plots. *Plant and Soil*, *319*(1), 235–246. https://doi.org/10.1007/s11104-008-9866-z

Brookes, P. C., Powlson, D. S., & Jenkinson, D. S. (1984). Phosphorus in the soil microbial biomass. *Soil Biology & Biochemistry*, *16*(2), 169–175. https://doi.org/10.1016/0038-0717(84)90108-1

Chandra, L. R., Gupta, S., Pande, V., & Singh, N. (2016). Impact of forest vegetation on soil characteristics: A correlation between soil biological and physico-chemical properties. *3 Biotech*, *6*(2), 188. https://doi.org/10.1007/s13205-016-0510-y

Chen, D., Li, J., Lan, Z., Hu, S., Bai, Y., & Niu, S. (2016). Soil acidification exerts a greater control on soil respiration than soil nitrogen availability in grasslands subjected to long-term nitrogen enrichment. *Functional Ecology*, *30*(4), 658–669. https://doi.org/10.1111/1365-2435.12525

Chen, X., & Chen, H. Y. H. (2019). Plant diversity loss reduces soil respiration across terrestrial ecosystems. *Global Change Biology*, *25*(4), 1482-1492. https://doi.org/10.1111/gcb.14567

Curtis, J. T., & McIntosh, R. P. (1950). The interrelations of certain analytic and synthetic phytosociological characters. *Ecology*, *31*(3), 434–455. https://doi.org/10.2307/1931497

Sundarapandian, S. M., & Dar, J. A. (2014). Variation in soil CO2 efflux in Pinus wallichiana and Abies pindrow temperate forests of western Himalayas, India. *Forest Research: Open Access, 3*(1). https://doi.org/10.4172/2168-9776.1000116

Dar, J. A., Ganie, K. A., & Sundarapandian, S. (2015). Soil CO_2 efflux among four coniferous forest types of Kashmir Himalaya, India. *Environmental Monitoring and Assessment*, *187*(11), 715. https://doi.org/10.1007/s10661-015-4927-2

Dar, J. A., & Sundarapandian, S. (2016). Patterns of plant diversity in seven temperate forest types of Western Himalaya, India. *Journal of Asia-Pacific Biodiversity*, *9*(3), 280–292. https://doi.org/10.1016/j.japb.2016.03.018

Fan, L. C., Yang, M. Z., & Han, W. Y. (2015). Soil respiration under different land uses in eastern China. *PloS one, 10*(4), e0124198. https://doi.org/10.1371/journal.pone.0124198

Fu, X., Shao, M., Wei, X., & Wang, H. (2013). Soil respiration as affected by vegetation types in a semiarid region of China. *Soil Science and Plant Nutrition*, *59*(5), 715–726. https://doi.org/10.1080/00380768.2013.821935

Han, T., Huang, W., Liu, J., Zhou, G., & Xiao, Y. (2015). Different soil respiration responses to litter manipulation in three subtropical successional forests. *Scientific reports, 5*, 18166. https://doi.org/10.1038/srep18166

Hanson, P. J., O'Neill, E. G., Chambers, M. L. S., Riggs, J. S., Joslin, J. D., & Wolfe, M. H. (2003). Soil respiration and litter decomposition. In P. J. Hanson & S. D. Wullschleger (Eds.), *North American temperate deciduous forest responses to changing precipitation regimes* (pp. 163–189). Springer. https://doi.org/10.1007/978-1-4613-0021-2_10

Jina, B. S., Bohra, C. P. S., Rawat, Y. S., & Bhatt, M. D. (2008). Seasonal changes in soil respiration of degraded and non-degraded sites in oak and pine forests of Central Himalaya. *Scientific World*, *6*(6), 89–93. https://doi.org/10.3126/sw.v6i6.2641

Joshi, M. (1995). Patterns of soil respiration in a temperate grassland of Kumaun Himalaya, India. *Journal of Tropical Forest Science*, 185–195.

Joshi, M., Mer, G. S., Singh, S. P., & Rawat, Y. S. (1991). Seasonal pattern of total soil respiration in undisturbed and disturbed ecosystems of Central Himalaya. *Biology and Fertility of Soils*, *11*(4), 267–272. https://doi.org/10.1007/BF00335846

Kara, Ö., Bolat, İ., Çakıroğlu, K., & Öztürk, M. (2008). Plant canopy effects on litter accumulation and soil microbial biomass in two temperate forests. *Biology and Fertility of Soils*, *45*(2), 193–198. https://doi.org/10.1007/s00374-008-0327-x

Li, Y., Xu, M., & Zou, X. (2006). Heterotrophic soil respiration in relation to environmental factors and microbial biomass in two wet tropical forests. *Plant and Soil*, *281*(1), 193–201. https://doi.org/10.1007/s11104-005-4249-1

Liu, M., Xia, H., Fu, S., & Eisenhauer, N. (2017). Tree diversity regulates soil respiration through accelerated tree growth in a mesocosm experiment. *Pedobiologia, 65*, 24-28. https://doi.org/10.1016/j.pedobi.2017.05.005

Liu, Y., Liu, S., Wang, J., Zhu, X., Zhang, Y., & Liu, X. (2014). Variation in soil respiration under the tree canopy in a temperate mixed forest, central China, under different soil water conditions. *Ecological Research*, *29*(2), 133–142. https://doi.org/10.1007/s11284-013-1110-5

Luo, J., Chen, Y., Wu, Y., Shi, P., She, J., Zhou, P., & Gilbert, J. A. (2012). Temporal-spatial variation and controls of soil respiration in different primary succession stages on glacier forehead in Gongga Mountain, China. *Plos One*, *7*(8), e42354. https://doi.org/10.1371/journal.pone.0042354

Michelsen, A., Andersson, M., Jensen, M., Kjøller, A., & Gashew, M. (2004). Carbon stocks, soil respiration and microbial biomass in fire-prone tropical grassland, woodland and forest ecosystems. *Soil Biology & Biochemistry*, *36*(11), 1707–1717. https://doi.org/10.1016/j.soilbio.2004.04.028

Mishra, S., Chaudhary, L. B., Jain, M. K., Kumar, V., & Behera, S. K. (2020). Interaction of abiotic factor on soil CO_2 efflux in three forest communities in tropical deciduous forest from India. *Environmental Monitoring and Assessment*, *191*(Suppl 3), 796. https://doi.org/10.1007/s10661-019-7689-4

Mohanty, R. B., & Panda, T. (2011). Soil respiration and microbial population in a tropical deciduous forest soil of Orissa, India. *Flora - Morphology, Distribution, Functional Ecology of Plants*, *206*(12), 1040–1044. https://doi.org/10.1016/j.flora.2011.07.009

Prasad, S., & Baishya, R. (2019). Interactive effects of soil moisture and temperature on soil respiration under native and non-native tree species in semi-arid forest of Delhi, India. *Tropical Ecology*, *60*(2), 252–260. https://doi.org/10.1007/s42965-019-00028-x

Qi, Y., & Xu, M. (2001). Separating the effects of moisture and temperature on soil CO_2 efflux in a coniferous forest in the Sierra Nevada mountains. *Plant and Soil*, *237*(1), 15–23. https://doi.org/10.1023/A:1013368800287

Raich, J. W., & Schlesinger, W. H. (1992). The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus B*, *44*(2), 81–99. https://doi.org/10.1034/j.1600-0889.1992.t01-1-00001.x

Raich, J. W., & Tufekciogul, A. (2000). Vegetation and soil respiration: Correlations and controls. *Biogeochemistry*, *48*(1), 71–90. https://doi.org/10.1023/A:1006112000616

Raina, A. K., & Gupta, M. K. (2009). Soil characteristics in relation to vegetation and parent material under different forest covers in Kempty forest range, Uttarakhand. *Indian Forester*, *135*(3), 331–341. https://www.cabdirect.org/cabdirect/abstract/20093149666

Rawat, M., Arunachalam, K., Arunachalam, A., Alatalo, J., & Pandey, R. (2019). Associations of plant functional diversity with carbon accumulation in a temperate forest ecosystem in the Indian Himalayas. *Ecological indicators, 98*, 861-868. https://doi.org/10.1016/j.ecolind.2018.12.005

Ruehr, N. K., & Buchmann, N. (2010). Soil respiration fluxes in a temperate mixed forest: Seasonality and temperature sensitivities differ among microbial and root-rhizosphere respiration. *Tree Physiology*, *30*(2), 165–176. https://doi.org/10.1093/treephys/tpp106

Ruehr, N. K., Knohl, A., & Buchmann, N. (2010). Environmental variables controlling soil respiration on diurnal, seasonal and annual time-scales in a mixed mountain forest in Switzerland. *Biogeochemistry*, *98*(1), 153–170. https://doi.org/10.1007/s10533-009-9383-z

Schlesinger, W. H., & Andrews, J. A. (2000). Soil respiration and the global carbon cycle. *Biogeochemistry*, *48*(1), 7–20. https://doi.org/10.1023/A:1006247623877

Singh, N., & Parida, B. R. (2019). Environmental factors associated with seasonal variations of night-time plant canopy and soil respiration fluxes in deciduous conifer forest, Western Himalaya, India. *Trees*, *33*(2), 599–613. https://doi.org/10.1007/s00468-018-1804-y

Tanaka, K., & Hashimoto, S. (2006). Plant canopy effects on soil thermal and hydrological properties and soil respiration. *Ecological Modelling*, *196*(1), 32–44. https://doi.org/10.1016/j.ecolmodel.2006.01.004

Vesterdal, L., Elberling, B., Christiansen, J. R., Callesen, I., & Schmidt, I. K. (2012). Soil respiration and rates of soil carbon turnover differ among six common European tree species. *Forest Ecology and Management, 264*, 185-196. https://doi.org/10.1016/j.foreco.2011.10.009

Vincent, G., Shahriari, A. R., Lucot, E., Badot, P.-M., & Epron, D. (2006). Spatial and seasonal variations in soil respiration in a temperate deciduous forest with fluctuating water table. *Soil Biology & Biochemistry*, *38*(9), 2527–2535. https://doi.org/10.1016/j.soilbio.2006.03.009

Walkley, A., & Black, I. A. (1934). An examination of the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, *37* (1), 29. https://doi.org/10.1097/00010694-193401000-00003

Yang, K., Yang, Y., Xu, Z., Wu, Q., & Hui, D. (2018). Soil respiration in a subtropical forest of southwestern China: Components, patterns and controls. *Plos One*, *13*(9), e0204341. https://doi.org/10.1371/journal.pone.0204341

Yohannes, Y., Shibistova, O., Abate, A., Fetene, M., & Guggenberger, G. (2011). Soil CO_2 efflux in an Afromontane forest of Ethiopia as driven by seasonality and tree species. *Forest Ecology and Management*, *261*(6), 1090–1098. https://doi.org/10.1016/j.foreco.2010.12.032

Yuste, J. Curiel, et al. (2003) “Interactive effects of temperature and precipitation on soil respiration in a temperate maritime pine forest.” *Tree physiology* 23.18 : 1263–1270.