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Soil Respiration Under Different Land Use Systems in Kumaon Region of Central Himalaya, India

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ABSTRACT
Soil respiration (SR) is chiefly controlled by microclimatic conditions, microbial activity, and land use management practices of the particular ecosystem. In the present study, SR was measured under three different land-use systems viz. arable land (AL), kitchen garden (KG), and peach orchard (PO) in the Almora and Nainital districts of Uttarakhand to observe the effect of soil temperature (ST) and soil moisture (SMC) on the rate of SR. The seasonal mean SR rate (g CO^2 m^{-2} h^{-1}) was 2.67 ± 0.33, 4.3 ± 0.06, 8.29 ± 2.59 for the year 2017-18, and 1.37 ± 0.28, 1.85 ± 0.05 and 2.27 ± 0.03 for the year 2018 19 in AL, KG and PO, respectively. Maximum SR was observed in PO followed by KG and AL. This study also found the spatial and temporal variations of SR in the selected land-use systems. The SR was positively correlated with SMC but negatively correlated with ST. Thus, the ST explained maximum variability of SR in the selected land-use systems. Overall, the results of this study clearly indicate that the microclimatic variables and land use management practices hav greater role in changes in SR of the studied region.

Key words: Central Himalaya, Kumaon sub-division, land use systems, field soil respiration, rabi crop season, soil moisture content, soil temperature.

INTRODUCTION

Soils are the major component of terrestrial ecosystem and have the potential to act either as net sources or net sinks of atmospheric carbon dioxide (CO_2) (Wang et al. 2003). As per the Kyoto Protocol, world soils are the most potential sink for the atmospheric CO_2. Globally, soils are the largest organic carbon (OC) reservoir that stores approximately two times carbon (C) as in vegetation and nearly three times as in atmosphere (Amundson 2001). The rate of decomposition and soil respiration processes determine carbon storage in any ecosystem (Dinakaran et al. 2014). Earlier studies based on statistical models have reported that around 78 to 108 Pg C yr^{-1} is released through soil respiration globally (Bond-Lamberty and Thomson 2010, Huang et al. 2020). The production rate of soil CO_2 is the index of total metabolic activity (Joshi et al. 1991). Soil respiration (SR) is comprised of autotrophic (root) respiration (Ra) and heterotrophic (microbial) respiration (Rh) leading to CO_2 production in terrestrial C cycle (Huang et al. 2020). SR is chiefly influenced by varied abiotic and biotic factors as soil climate factors (Huang et al. 2020), temperature (Wan 2008), moisture (Bolten et al. 2009), fertility (Butnor et al. 2003), plant productivity (Running et al. 2000, Mitra et al. 2019), litter input (Hanson et al. 2000), availability of C compounds on soil microbiota (Seto and Yanagiya 1983), population size of microbiota (Rai and Srivastava 1981) and soil properties (Alekseev et al. 2018). In addition, different anthropogenic activities as land use change (Ebrahimi et al. 2019), addition of phosphorus (Feng and Zhu 2019) and nitrogen (Chen et al. 2019) etc. could also have deep impact on SR. Land use change can deeply influence SR by altering vegetation structure and composition, local microclimate and edaphic properties (Huang et al. 2020). Thereby, it is vital to understand the dynamics of SR for further improvement and amendment of ecosystem management services.

The mountainous regions of Central Himalaya with different elevational gradients are characterized by varied biotic and climatic characteristics within short geographic distances (Tiwari et al. 2021). The SR in Central Himalayan region is chiefly influenced by vegetation (Bargali et al. 1992, Rawat et al. 2021), plant traits and soil properties (Joshi et al. 1991, Rawat et al. 2020) and climatic conditions such as temperature (ST) and precipitation (SMC) (Tiwari et al. 2021). Moreover, the studies of Bargali et al. (1992) and Tiwari et al. (2021) have reported that seasons and temperature affect the rates of soil respiration in Himalaya that in turn likely to have a deep impact on soil C-storage and CO_2 efflux (Singh and Parida 2019). There is a paucity of information on SR in different land use systems of Kumaon region of Central Himalaya. The major objectives of this study are (1) to determine the SR in different land use systems, and (2) to understand the effect of soil temperature (ST) and moisture content (SMC) on SR in different land used systems of Central Himalaya.

MATERIAL AND METHODS

The present study was conducted in three prominent land use systems viz. arable land (AL), kitchen garden (KG) and peach orchard (PO) in the Almora and Nainital districts of Kumaon sub-division of Uttarakhand located between 29°52' N and 31°25' N latitudes and 77°45' E and 81°E longitudes that constitutes a part of Central Himalaya (Table 1 and Fig. 1). Soils in this region are predominantly classified as Nitosols/ Luvisols under Udalfs soil order (NBSS & LUP 1985, Table 1). The study area has temperate monsoon type of climate characterized by short and warm summer (April to mid-June), moist and wet rainy seasons (mid-June to mid-September) and severe winter (October to March end, Negi and Singh 1993). During the study period, the study area received an annual precipitation of 129.34 and 109.90 mm with 22.33 and 21.79°C as mean maximum, 12.08 and 10.62°C as mean minimum air temperature during 2017-18 and 2018-19, respectively (meteorological data were collected from meteorological lab, ICAR-NBPGR R/S, Bhowali 2017, 2019). Most of the annual precipitation was received during the monsoon season.

Soil sampling and measurement of soil respiration

The soil sampling was done on monthly basis for a period of two rabi seasons. The study was conducted from November 2017 to April 2018 and December 2018 to May 2019 and soil respiration (SR) was measured in the first week of every month in all the selected study sites. SR was measured using alkali absorption method (Gupta and Singh1977, Joshi et al.1991, Joshi 1994) using black paper wrapped plastic cylinders (14.5 × 20 cm) with lids that can be sealed at the top, inserted approximately 5 cm into ground. Three replicates of the cylinders on each experimental plot were set up with three blanks or control cylinders, capped with airtight lids. The vegetation within the area of cylinder was clipped and removed along with the debris and litter before

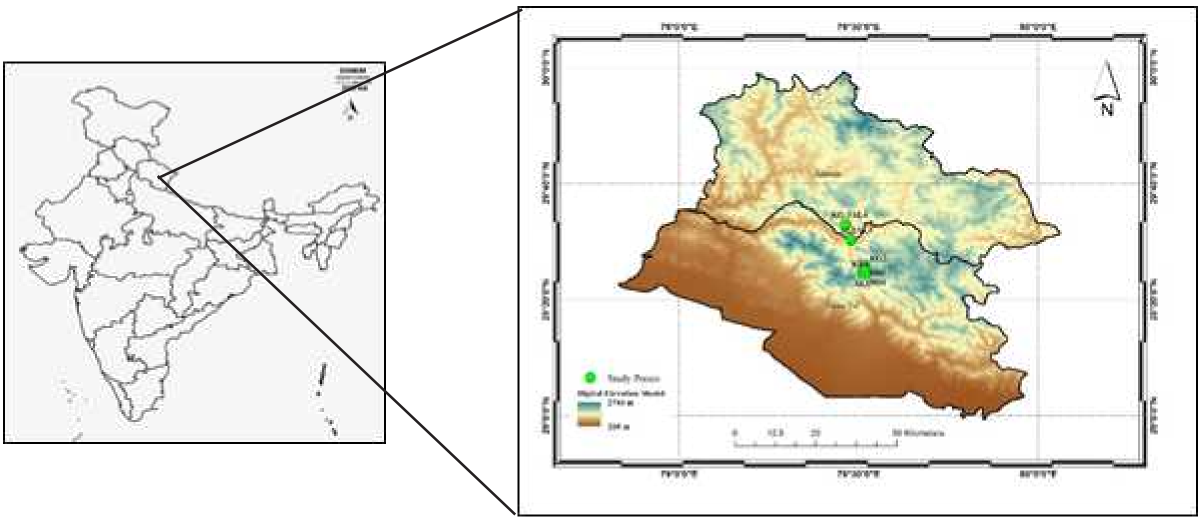

Figure 1. DEM map of Uttarakhand, India, showing the study sites

Table 1. Characteristics of the experimental sites under different land use systems of Kumaon sub-division of Central Himalaya, Uttarakhand

S.No.	Site name	Site type	Site Code	District	Block	Latitude	Longitude	Elevation (in m)	Soil type	Site description	Vegetation
1.	**ICAR-NBPGR R/S Bhowali**	**AL**	**AL1**	Nainital	Betalghat	N29°24’30.2"	E79°30’46.9"	1470	Loam	Irrigated conventional Urea was added	Wheat, barley and lentil
2.	**Syalikhet**	**AL**	**AL2**	Almora	Tarikhet	N29°32’55.6"	E79°27’49.6"	1209	Silt Loam	Rainfed organic	Intercropping of wheat and legumes (lentils)
3.	**Syalikhet**	**KG**	**KG3**	Almora	Tarikhet	N29°32’55.2"	E79°27’48.8"	1214	Silt Loam	Rainfed organic	Potato, onion, coriander, pea and spinach
4.	**Surifarm**	**AL**	**AL3**	Nainital	Betalghat	N29°30’18.1"	E79°28’38.4"	941.3			Wheat
5.	**GBPUAT R/S Majhera**	**AL**	**AL4**			N29°30’11.2"	E79°28’45.4"	883.8	Sandy Loam	Irrigated conventional urea/DAP was added.	Wheat
6.	**Niglat**	**PO**	**PO1**	Nainital	Betalghat	N29°24’28.7"	E79°30’54.9"	1534	Loam	Managed rainfed organic	Legumes were intercropped with peach trees
7.	**Niglat**	**KG**	**KG1**	Nainital	Betalghat	N29°24’27.5"	E79°30’54.7"	1536	Loam	Rainfed organic	Coriander and garlic.
8.	**Kainchidham**	**PO**	**PO2**	Nainital	Betalghat	N29°25’20.4"	E79°30’52.7"	1347	Sandy Loam	Rainfed unmanaged	Peach orchard.
9.	**Kainchidham**	**KG**	**KG2**	Nainital	Betalghat	N29°25’19.3"	E79°30’54.4"	1367	Sandy Loam	Irrigated organic	Garlic, mustard, potato, and pea

Note: *AL*: Arable Land; ICAR-National Bureau of Plant Genetic Resources R/S Bhowali (AL1 = NBPGR B, NBPGR W and NBPGR L), Syalikhet (AL2 = SYALI), Surifarm (AL3 = SURI) and Govind Ballabh Pant University of Agriculture and Technology R/S Majhera (AL4 = RSM); *KG*: Kitchen Gardens; Niglat kitchen garden (KG1 = NKG), Kainchidham kitchen garden (KG2 = KKG) and Syalikhet kitchen garden (KG3 = SKG); *PO*: Peach Orchards; Niglat peach orchard (PO1 = NPO) and Kainchidham peach orchard (PO2 = KPO).

performing the experiment. The CO_2 that evolved was absorbed in a 50 ml vial containing 20 ml of 1N NaOH placed on a tripod stand kept close to the surface of ground enclosed within the cylinder for duration of a little more than 24 hours to avoid diurnal variations. After more than 24 hours, we estimated the amount of CO_2 trapped in alkali by titrating it against 1N HCl, using phenolphthalein as an indicator (Harris and Van Bavel 1957). The mass/volume/amount of the CO_2 evolved was estimated by using the formula (Misra 1968):

$$\text{mg } CO_2 = V \times N \times 22$$

In the above equation, V stands for titration of blank minus the sample titration, N is the normality of HCl and 22 is the equivalent weight of CO_2. SR was expressed using the unit mg CO_2 m^{-2} h^{-1}. ST was recorded by using soil thermometer and moisture by gravimetric method (oven dry at 105°C till constant weight was obtained). The soil texture was determined manually by international pipetting method and pH through a pH meter (Eutech, Allen et al. 1974). Soil carbon (C) and total nitrogen (N) concentrations were determined using CHNS Analyzer (Elementar GmbH, Germany). Soil enzymes as ß-glucosidase (BG, Eivazi and Tabatabai 1988), dehydrogenase (DHA, Casida 1977), and urease (URE, Kandeler and Gerber 1988) were assayed in the collected samples using standard methods.

Statistical analysis

Analysis of variance (ANOVA) was conducted to determine the variations in SR and other climatic, chemical and biological variables among the selected land use systems. The significance was tested at $P < 0.05$. Correlation analysis was conducted using PAST ver. 4.04 for windows to study the relationship between SR and selected factors.

RESULTS

Climate variables

The minimum air temperature was observed during January (~1°C) and maximum in June (~28°C). The temperature increased gradually during April and started declining again during November. Precipitation was maximum during the month of July (~540.50 mm) and October, November and December were devoid of any precipitation. While precipitation values were cumulative of all days for a month, the air temperature values were mean of the daily values for maximum and minimum for January 2017 to December 2019 (Fig. 2).

Soil chemical parameters

The mean monthly values of soil C and N

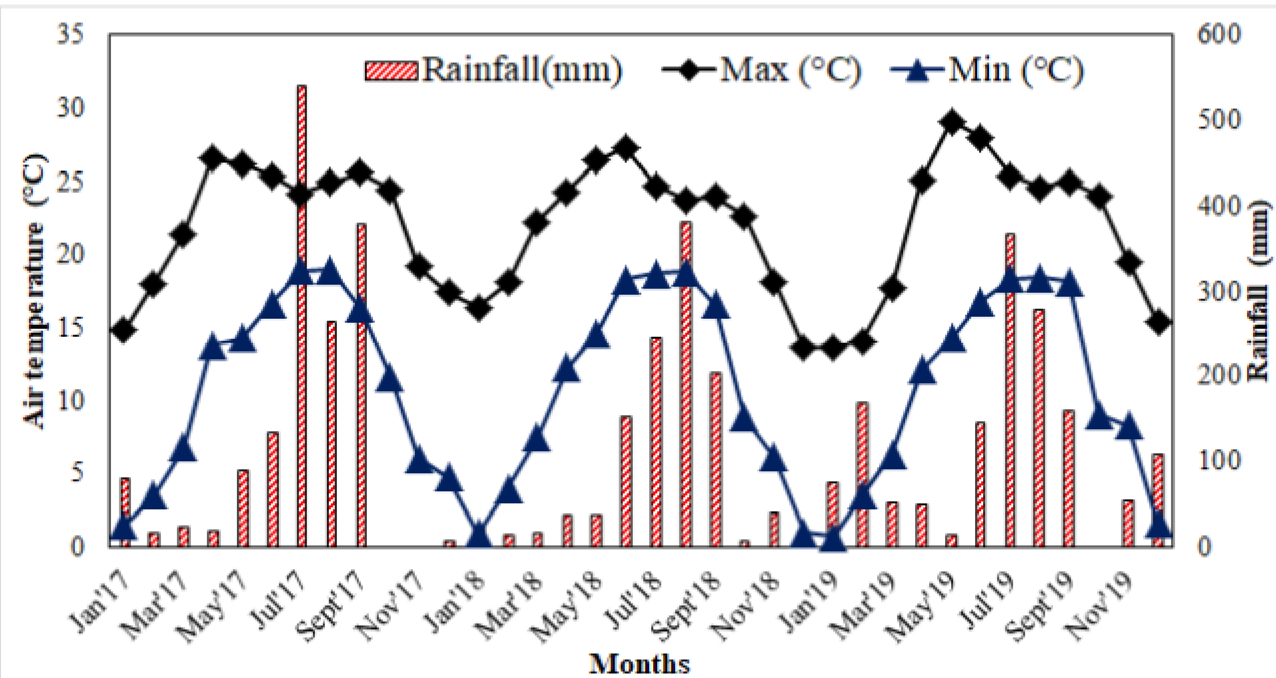

Figure 2. Monthly variation in precipitation (mm) and temperature (°C) during the study period from January 2017 to December 2019

concentrations (g kg^{-1}) at 0–10 cm soil depth of the selected land use systems along with their statistical significance are given in the Tables 2 and 3. Among all the studied land use systems, soil C and N contents for the years 2017–18 and 2018–19 were found to be significantly higher in peach orchard (PO) land use system and lower in arable (AL) land use systems.

Soil moisture content (SMC), temperature (ST) and respiration (SR)

The mean values of soil temperature (ST), soil moisture content (SMC), soil respiration (SR) and the other parameters of the studied land use systems are given in Table 2 and the spatial and temporal variations in each of the selected land use system in Figs. 3a-i and 4a-i.

Both ST and C:N ratio were not significantly different across the three land use systems viz. arable land (AL), kitchen garden (KG) and peach orchard (PO) during the study period. Interestingly, the factors such as soil pH, C, N and enzymatic activities such as dehydrogenase (DHA), and urease (URE) were significantly different (P < 0.05) across the three land use systems for 2017–18 and 2018–19 (Table 2).

Table 3. Statistical significances of the effects of selected land use systems and sites on varied soil chemical and biological variables based on ANOVA (numbers are F values)

Parameter	2017-18	2018-19
df	2	2
ST	0.103^{NS}	0.282 ^{NS}
SMC	2.39^{NS}	4.975*
pH	10.49*	11.91*
SR	2.80^{NS}	7.26*
BG	30.88*	2.76^{NS}
DHA	7.358*	10.37*
URE	8.506*	14.09*
C	30.01*	45.26*
N	38.14*	63.42*
C:N ratio	1.38 ^{NS}	2.81 ^{NS}

Note: ST - Soil temperature; SMC - Soil moisture content; SR - Soil respiration; BG- â-glucosidase, DHA- Dehydrogenase, URE- Urease, C- soil carbon; N - Soil nitrogen; *P < 0.05. *NS*: Non-significant

Table 2. Descriptive statistics of varied soil biological and chemical parameters in the selected land use systems of Kumaon sub-division of Central Himalayan region for the rabi season of 2017–18 and 2018–19.

Land use	Year	ST	SMC	pH	SR	BG	DHA	URE	C	N	C:N ratio
AL	**2017–18**	16.76 ± 1.14	9.14 ± 0.95	6.07 ± 0.25	2.67 ± 0.33	88.75 ± 8.92	220.47 ± 59.19	281.35 ± 92.47	21.33 ± 4.63	1.93 ± 0.32	10.88 ± 0.97
	2018–19	18.36 ± 1.01	8.0 ± 0.86	6.09 ± 0.21	1.37 ± 0.28	189.86 ± 87.53	211.31 ± 95.04	330.70 ± 18.44	20.18 ± 3.84	1.91 ± 0.29	10.32 ± 0.56
KG	**2017–18**	17.57 ± 1.44	12.89 ± 1.09	5.68 ± 0.42	4.3 ± 0.06	192.08 ± 21.16	341.67 ± 23.88	278.51 ± 19.02	35 ± 3.05	3.03 ± 0.10	11.74 ± 0.91
	2018–19	19.38 ± 1.57	10.78 ± 1.66	5.67 ± 0.14	1.85 ± 0.05	120.97 ± 10.66	189.67 ± 43.89	290.28 ± 16.98	37.26 ± 2.58	2.99 ± 0.22	12.62 ± 0.34
PO	**2017–18**	17.58 ± 0.46	12.42 ± 2.86	6.57 ± 0.29	8.29 ± 2.59	134.88 ± 9.08	467.66 ± 71.60	553.01 ± 69.34	46.14 ± 8.92	3.97 ± 0.75	11.64 ± 0.01
	2018–19	18.82 ± 1.70	13.18 ± 0.85	6.54 ± 0.32	2.27 ± 0.03	124.25 ± 2.96	445.12 ± 43.09	550.17 ± 32.48	52.93 ± 3.78	4.77 ± 0.22	11.13 ± 0.26

Note: *AL*: Arable land, *KG*: Kitchen garden, *PO*: Peach orchard, *ST*: Soil temperature, *SMC*: soil moisture content, *pH*: soil acidity or alkalinity, *SR*: soil respiration, *BG*: â-glucosidase, *DHA*: Dehydrogenase, *URE*: Urease, *C*: soil carbon content, *N*: soil nitrogen content, *C:N* ratio: soil carbon to nitrogen ratio. Each value represents the mean ± SE, n = 3. Values followed by different letters are significantly different from each other across the selected land use system (P < 0.05).

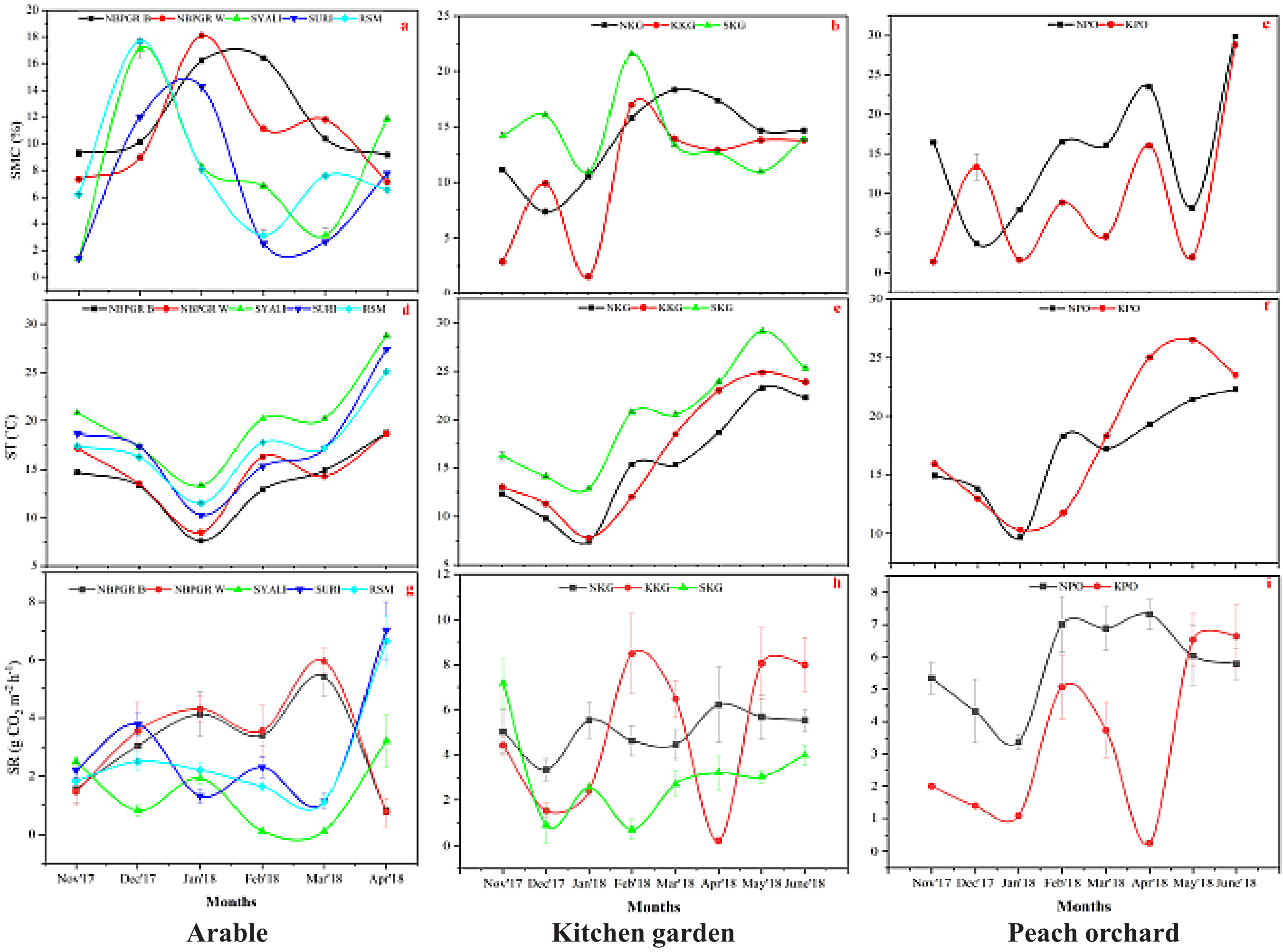

Figure 3. Monthly variation in soil (**a-c**) moisture content (SMC), (**d-f**) temperature (ST) and (**g-i**) respiration (SR) of the selected land use systems during the year 2017–18.

Note: AL1 = *NBPGR B*: NBPGR barley; *NBPGR W*: NBPGR wheat; AL2 = *SYALI*: Syalikhet wheat; AL3 = *SURI*: Surifarm wheat; AL4 = *RSM*: GBPUAT R/C Majhera wheat, PO1 = *NPO*: Niglat peach orchard; PO2 = *KPO*: Kainchidham peach orchard, KG1 = *NKG*: Niglat kitchen garden; KG2 = *KKG*: Kainchidham kitchen garden and KG3 = *SKG*: Syalikhet kitchen garden.

Soil pH was significantly higher for PO (~6.6) and lowest for KG (~5.7). SR was maximum for PO during both the studied years. In 2017–18 and 2018–19, SR (g CO_2 m^{-2} h^{-1}) was highest for PO (8.29 ± 2.59; 2.27 ± 0.03) and lowest for AL (1.37 + 0.28; 2.27 ± 0.28). Likewise, significant differences were also observed for the selected soil factors such as C (g kg^{-1}), N (g kg^{-1}), C:N ratio and enzymatic activities such as DHA (µg TPF g^{-1} dwt^{-1} hr^{-1}) and URE (µg NH_4-N g^{-1} dwt^{-1} $2h^{-1}$) across the land use systems during the study period. Significantly high amounts of C ($P < 0.05$) (46.14 ± 8.92; 52.93 ± 3.78 and 21.33 ± 4.63; 20.18 ± 3.84), N (3.97 ± 0.75; 4.77 ± 0.22 and 1.93 ± 0.32; 1.91 ± 0.29) and DHA (467.66 ± 71.60; 445.12 ± 43.60 and 220.47 ± 59.19; 211.31 ± 95.04) were recorded for PO and lowest for AL (Tables 2 and 3). Moreover, URE was also significantly high in PO (553.01 ± 69.34; 550.17 ± 32.48) and low in KG (278.51 ± 19.02; 290.28 ± 16.98) for the study period.

SR showed positive correlation with SMC across the land use systems studied but negative correlation with ST. During 2017-2018 significant ($P < 0.05$) positive correlation was observed between DHA and ST; SMC and C; N, C, DHA and URE (Fig. 5a). Likewise, in 2018-2019 significantly strong negative correlation was observed between sand, silt and clay while strong positive correlation was observed between SMC, C, N, DHA and URE (Fig. 5b).

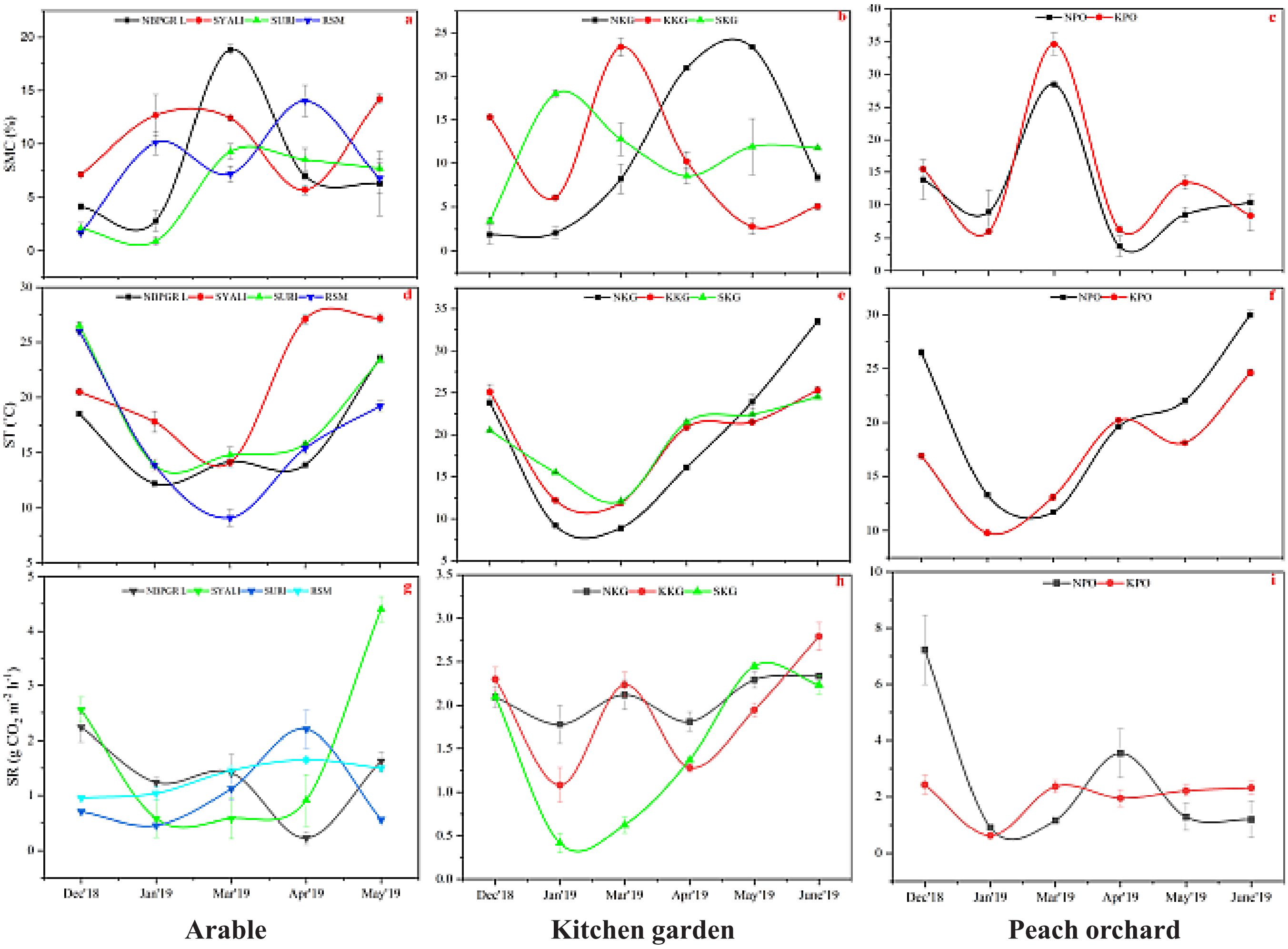

Figure 4. Monthly variation in (**a-c**) soil moisture content (SMC), (**d-f**) temperature (ST) and (**g-i**) respiration (SR) of the selected land use systems for the year 2018–19.

Note: AL1 = *NBPGR L*: NBPGR lentil; AL2 = *SYALI*: Syalikhet wheat; AL3 = *SURI*: Surifarm wheat; AL1 = *RSM*: GBPUAT R/C Majhera (Wheat), PO1 = *NPO*: Niglat peach orchard; PO2 = *KPO*: Kainchidham Peach orchard, KG1 = *NKG*: Niglat kitchen garden; KG2 = *KKG*: Kainchidham kitchen garden and KG3 = *SKG*: Syalikhet kitchen garden.

DISCUSSION

Soil respiration

Across the three selected land use systems**,** the highest rate of CO_2 emission was observed under peach orchard (PO) and kitchen garden (KG) rather than arable land (AL). The present study is in agreement with the previous findings that conversion of forest into cropland along with associated management practices such as tillage, application of fertilizers have deep impact in alterations of soil organic carbon (SOC) and so on soil respiration (SR) (Wang et al. 2007, Li et al. 2012, Tian et al. 2013, Neha et al. 2020). Sheng et al. (2010) suggested that substrate availability (e.g., SOC and soil nutrients) and soil C input (viz. fine root turnover and litterfall) through vegetation also govern the SR in natural and anthropogenically managed ecosystems. The lower rate of CO_2 efflux for the disturbed arable land (AL) than the other land use systems viz. peach orchard (PO) or kitchen garden (KG) in this study was in agreement with the findings of Joshi et al. (1991). The decline in SR in AL than PO or KG systems could be further explained by reduction of SOC content in topsoil, litter input that in turn are governed by plant productivity. Furthermore, soil moisture content (SMC), C and N concentrations in soils under PO and KG were

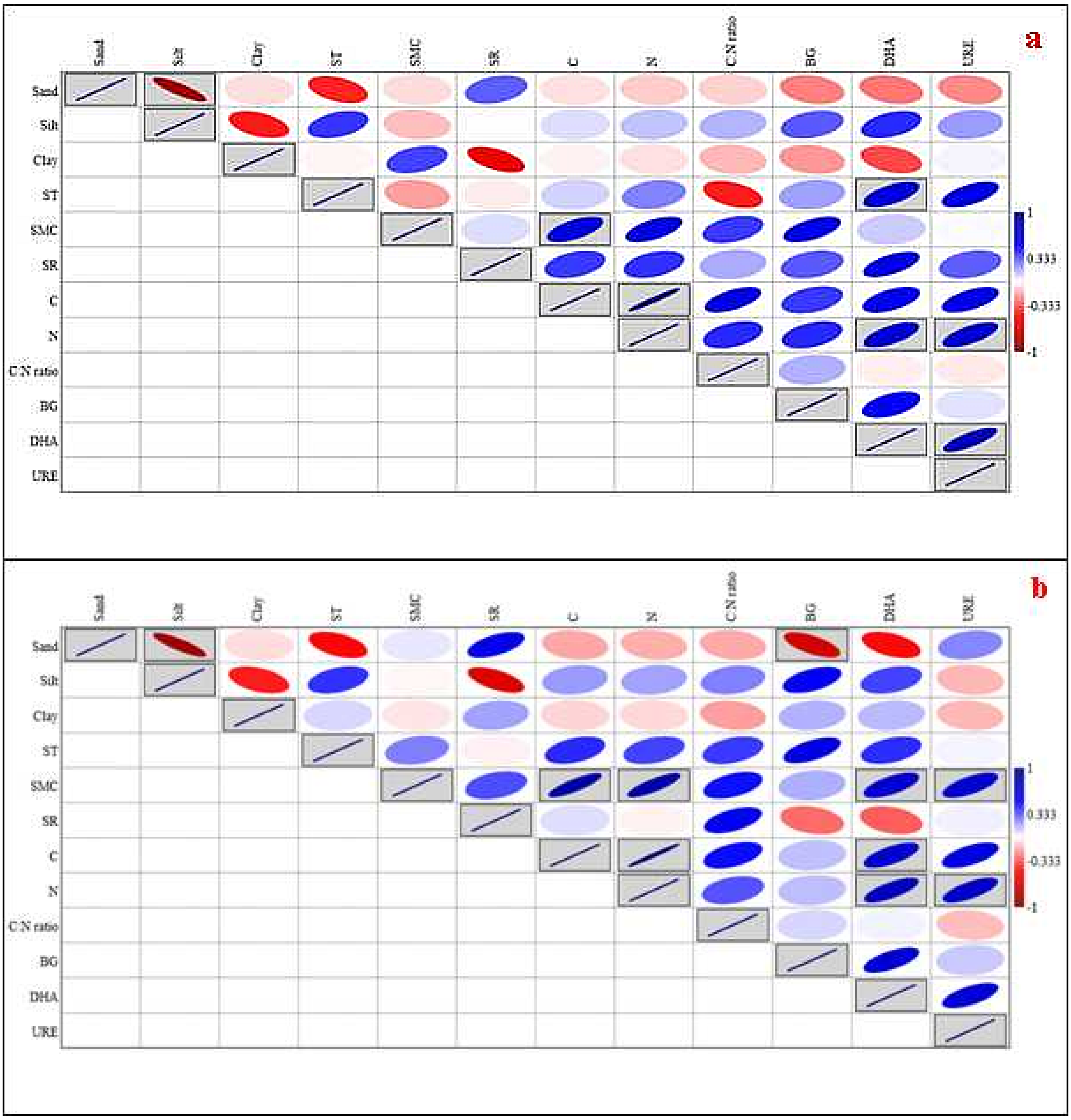

Figure 5. Correlation between varied soil abiotic and biotic parameters of the different selected land use systems for the years (a) 2017–18 and (b) 2018–19, respectively

comparatively higher than in AL thereby exceeding CO_2 emission (Joshi et al. 1991). The soil C and N contents provided the source of energy and protein, respectively, for microbial growth and thus played pivotal role in influencing SR (Joshi et al. 1991).

In the present study the highest rates of SR were recorded during spring (Feb-April) and monsoon (May-June) seasons while during the winter season (Nov-Jan) characterized with lowest temperature they were low. The increase in the rates of SR during spring and monsoon seasons could be attributed to the increase in soil temperature (ST) and soil moisture content (SMC) regimes. Decline in ST would have resulted in decreased microbial activity and SR during winter season. The results of this study are in agreement with the findings of Joshi et al. (1991), who also reported a similar trend of SR during winter season. Since the farming practices in Central Himalaya are generally farmyard manure (FYM) based (Semwal et al. 2004, Chandra et al. 2021) and the declined SR during winter resulted in low microbial activity which could further lead to accumulation of unutilized soil organic matter (SOM). The process of heterotrophic SR is generally regarded as a measure of total microbial activity that indicates the rate of SOM decomposition (Pregitzer et al. 2008). The quantity of SOM is generally affected by different land use management practices of cultivation that break the soil aggregates and release the adsorbed OM for decomposition (Elliot 1986, Six et al. 1998). Cultivation and its associated practices generally lead to lose as much as 20 – 50% of SOC, thereby affecting the soil C stock (Guo and Gifford 2002, Smith et al. 2008).

Apart from climatic factors as ST and SMC, the variations in the rates of SR could also be attributed to differences in edaphic factors such as soil microbial C and root growth that in turn govern the microbial activities (Lou et al. 2004, Adachi et al. 2006). Among the selected land use systems, soils of AL, viz. NBPGR barley (NBPGR B) and NBPGR wheat (NBPGR W), and PO, viz. Niglat peach orchard (NPO) were under high moisture regime that could be due to periodic irrigation of fields and/or random regional precipitation events. Even the temporal fluctuations in rates of SR in KG were due to variations in SMC and ST caused by such random regional precipitation events or periodic irrigation. The noticeable peaks in SR during the months of March, April and June in the studied land use systems coincided with the rise in ST and SMC as evident from the meteorological data.

Among the three land use systems the response of precipitation event on SR appeared to be more on the sites that were under regular management practices like tilling, irrigation, levelling (viz. Indian Council of Agricultural Research-National Bureau of Plant Genetic Resources R/S, Bhowali (ICAR-NBPGR; AL1), Niglat kitchen garden (NKG; KG1) and Niglat peach orchard (NPO; PO1)) rather than the less managed or non-disturbed sites (Syalikhet (SYALI; AL2), Surifarm (SURI; AL3), G.B. Pant University of Agriculture and Technology R/S, Majhera (RSM; AL4), Kainchidham kitchen garden (KKG; KG2), Syalikhet kitchen garden (SKG; KG3) and Kainchidham peach orchard (KPO; PO2)). Rey et al. (2011) had also reported greater influence of precipitation on degraded lands as compared to the non-degraded sites. The precipitation causes breaking down of the soil aggregates which leads in surge of CO_2 release from C and oxidation of the SOM, (Adu and Oades 1978). Interestingly, no significant difference was observed for SR across the selected study sites in 2017-18 that could be attributed to having similar moisture conditions. However, the mean values of SR for the three selected land use systems, i.e., AL, KG and PO were found to be low during 2018-19 than 2017-18 and as evident from the meteorological data that could be attributed to low rainfall (SMC) in the latter year.

Both SMC and ST are important factors that influence the rate of SR (Jia et al. 2006, Chang et al. 2014, Tiwari et al. 2021). However the variations in the rates of SR could also be attributed to differences in edaphic and biological factors as soil microbial C and root growth that in turn govern the microbial activities (Lou et al. 2004, Adachi et al. 2006). The correlation analysis of the present study is also in agreement with the findings of previous studies as Bargali et al. (1992) showed that the rate of SR was positively correlated to factors such as soil C, N and SMC. The correlation analysis of this study also confirmed that SR was positively controlled by SMC rather than ST. Moreover, the decrease in SR during winter was chiefly due to reduction in ST leading to low metabolic activities of soil microbiota. This study also reaffirmed that the SR was also influenced by soil C and N contents that provide the source of energy and protein, respectively, to microbial growth (Joshi et al. 1991). The relationship between SR, soil dehydrogenase activity (DHA) and other selected soil enzymes as, â - glucosidase (BG) and urease (URE) also indicated the importance of soil microbes (Skujinš 1973, Woliñska and Stêpniewska 2012) in SR.

Moreover, the increased SR during summer could be due to the enhanced soil microbial activity that was chiefly governed by higher SMC, C and N contents (of organic matter; OM) as these were not the limiting factors. Interestingly, the findings of Conant et al. (2004) showed that ST near 28°C is generally considered as optimum temperature for microbial activity thereby resulting in increased rate of SR. Higher or lower ST than that of the optimum mostly resulted in lower SR. Thus, the decline in ST resulted in reduced SR by influencing the soil microbial activity (Curiel Yuste et al. 2007, Bao et al. 2016) and would result in accumulation of manure added during the rabi season. Therefore, in this study ST is dominantly the major factor influencing SR in the Central Himalayan region and SMC is enhancing the response of SR to ST during rabi crop season. Hence, the current study indicates that SR is chiefly modulated by ST than SMC in Kumaon sub-division of Central Himalaya during rabi season.

Relation between soil dehydrogenase activity (DHA) and soil respiration (SR)

Soil dehydrogenase activity (DHA) is generally used as an indicator of microbial activities due to its occurrence in viable microbial cells (Nannipieri et al. 2011). Generally, triphenylte trazolium chloride (TTC), a dye-based laboratory method of Casida (1964) is used for soil DHA determination. Several studies have attempted previously to correlate the DHA activity with that of the other biological activities of arid region and well irrigated cultivated soils. However, interestingly in case of cultivated and well irrigated soils the correlation of DHA with the biological parameters was reported to be feeble than the soils under arid conditions (Skujinš 1973). Some of the earlier studies have reported a positive relationship between DHA and SR in the Himalayan region (Shukla et al. 1989, Arunachalam et al. 1999, Rajput et al. 2019). The results of the current study are in agreement with some of the previously reported studies showing that DHA activity was high in forest land use systems than that of cultivable lands (AL or KG) (Acosta-Martinez et al. 2007, da Silva et al. 2012, Araújo et al. 2013, Meena et al. 2020). The monthly and yearly fluctuations in DHA activity could be attributed to availability of nutrients, soluble SOC, increased microbial activity (Adak et al. 2014) that in turn is influenced by ST (Piao et al. 2000), SMC (Paul and Clark 1996), and other unknown ecological interactions or by composition of the soil microbiota (Beyer et al. 1993) thereby impeding valid ecological comparisons of soils.

CONCLUSIONS

The SR rate showed spatial and temporal variations during the studied period of rabi season and it was greatly influenced by abiotic factors viz. soil moisture content (SMC), soil and temperature (ST) of the selected land-use systems. The SR rate was positively correlated with SMC. Moreover, at the temporal scale, i.e., monthly or seasonal scales, the effect of ST on SR was stronger than SMC in the selected land-use systems. The findings of this study suggest that ST was the main driving factor that governs as well as causes variability in SR during rabi season in the Central Himalayan region. More studies are warranted to understand the effects of land use and land cover changes on soil respiration in the Central Himalaya.

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Authors' Contributions: KV and JD planned the work and executed. Lab analysis was completed with the participation of HC and TN. KSR supervised the work. All authors wrote, read and approved the manuscript.

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