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Appraisal of different land use systems for heterotrophic respiration in a Karst landscape

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ABSTRACT

Soil respiration, particularly heterotrophic respiration (RH), is a potent source of carbon dioxide (CO_2) in the atmosphere. The current research focuses on the evaluation of RH for six land use systems including sloping cropland (SC), shrub land (SD), grassland (GD), shrub & grassland (SGD), newly abandoned cropland (NC) and afforested forest (AF). Heterotrophic respiration showed a diverse seasonal pattern over a year long period that was affected by various soil properties and climatic variables across the six land use systems in a subtropical Karst landscape. The lowest RH scores were found in the SD site (annual cumulative soil CO_2 flux: 2447 kg C ha^{-1}), whereas the maximum heterotrophic respiration occurred in the SF site (annual cumulative soil CO_2 13597 kg C ha^{-1}). The values of RH were: SC site: 3.8–191.5 mg C m^{-2} h^{-1}, NC site: 1.04–129 mg C m^{-2} h^{-1}, GD site: 3.6–100.7 mg C m^{-2} h^{-1}, SGD site: 0.3–393.5 mg C m^{-2} h^{-1}, SD site: 3–116 mg C m^{-2} h^{-1}, and SF site: 10.6–398.2 mg C m^{-2} h^{-1}. Highly significant ($p \leq 0.01$) and positive correlations between RH rate and soil temperature were found for the studied land use types (correlation coefficients as follows; SC: 0.77, NC: 0.61, GD: 0.283, SGD: 0.535, SD: 0.230, SF: 0.85). However, water filled pore space (WFPS), NH_4^+, NO_3^-, dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) concentrations showed varied (positive and negative) correlations with RH. The overall results show that soil temperature can be considered as the most limiting factor for RH among all the sites studied in the present research. In these environments, soil heterotrophic respiration significantly correlated with soil temperature, highlighting the significance of climate on heterotrophic respiration.

1. Introduction

Global soils contain approximately 1500 Pg of carbon (considering up to 100 cm soil depth), which is two folds greater than the amount of carbon (C) in the atmosphere (Liu et al., 2011; Tang et al., 2020). A minor variation in soil C can substantially affect the atmospheric CO_2 concentration and, therefore, climate change and global warming (Amelung et al., 2020). Soil respiration has great contribution to the atmospheric CO_2 concentration (Jian et al., 2022; Meeran et al., 2021; Schlesinger and Andrews, 2000). The share of soil respiration to annual global CO_2 emissions is relatively much higher than the emissions from fossil fuel combustion (Meeran et al., 2021). Thus, alterations in soil respiration will prominently trigger the C cycling in ecosystems, and can ultimately influence global climate.

Soil respiration is the sum of heterotrophic and autotrophic respirations (Lei et al., 2021). Autotrophic respiration is derived from rhizosphere and roots of plants, and is mainly affected by several variables including biomass of fine roots, crop age, native nutrient status, soil moisture and temperature (Zheng et al., 2021). Soil heterotrophic respiration (RH) can be described as the loss of C from soil as a result of

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decomposition of organic materials by microorganisms (Bond-Lamberty et al., 2018). It is one of the principal but the utmost indeterminate components of C cycling in terrestrial ecosystems (Zhang et al., 2019). Heterotrophic respiration is regulated by a variety of environmental factors, among which soil moisture and temperature are identified as the most influencing ones (Li et al., 2017; Yan et al., 2018), although their impacts on heterotrophic respiration are inconsistent. RH was identified as negatively correlated with soil organic carbon (SOC) in soils of Mosoo bamboo (*Neosinocalamus affinis*) forest (Tang et al., 2016), whereas the RH fluxes positively correlated with SOC in temperate regions having similar plantation (Wang and Yang, 2007).

Soil physical properties are other key factors controlling heterotrophic respiration. Soil texture and bulk density are recognized as influential for soil nutrients (Freschet et al., 2017), causing indirect effects on heterotrophic respiration. Nevertheless, it is still unclear how soil physical properties affect RH with different land use systems. In addition, additional information is needed on how heterotrophic respiration is mediated by climatic variables and soil physicochemical properties.

Soil temperature is an important variable controlling the decomposition rate of soil organic matter, which affects seasonal dynamics of labile and readily available C and RH in different land use systems (Naidu et al., 2021). However, the variability of RH for different land uses remains a topic for research, with some reports indicating that recalcitrant SOM is not sensitive to changes in temperature (Giardina and Ryan, 2000), others signifying that non-labile SOM is much more respondent to temperature than labile SOM (Knorr et al., 2005), or that labile and non-labile SOMs have a similar behavior as response to temperature changes (Fang et al., 2005). Besides the soil and climatic factors, some others, such as vegetation (stand intensity and type), primary production, litter-fall, are identified as affecting heterotrophic respiration (Ikkonen et al., 2020; Yan et al., 2005). Biotic factors influence heterotrophic respiration through the changes of soil micro-environment as well as the quantity and quality of C return (Shi et al., 2020).

Karst landscape in South China is generally considered as extensively deteriorated ecological system, specifically in context of soil degradation (Chen et al., 2020). To improve soil properties, the strategy of afforestation on severely deteriorated lands has been largely imposed in Karst areas of South China. Plantation of trees on degraded land is one of the key programs for the sustainable development in the Karst region of China (Chen et al., 2020). Such regional planning for establishment of a forest can have several advantages, including prevention of erosion soil, controlling desertification, and increasing SOC (Cheng et al., 2016). To note that there is still lack of information on RH from various land use systems in the Karst area of South China.

In view of the previous background, the present research was designed to evaluate seasonal and annual RH rates of various land use systems not previously investigated, specifically focusing on Karst landscapes. The study was conducted to investigate (1) how heterotrophic respiration changes with different land use systems, (2) how some variables (such as soil temperature, moisture, mineral nitrogen, organic carbon and nitrogen) influence heterotrophic respiration, and (3) which variable is the most influential to drive heterotrophic respiration.

2. Material and methods

2.1. Description of the study sites

In the present research, areas subjected to different land use types were included in the experimental design. The studied land use sites are located in Puding County (26°22′5″ N, 105°45′10″ E) at Chinese Academy of Sciences, Anshun city, Guizhou province, China. The climate of the site is typically characterized as subtropical humid and monsoonal (Chen et al., 2020). Based on the data from 2007 to 2017, the study site has an average annual precipitation of 1378.2 mm and average annual temperature of 15.1 °C (Chen et al., 2020).

Six sites with different land use including sloping crop-land (SC), shrub-land (SD), grassland (GD), shrub & grassland (SGD), newly abandoned cropland (NC) and afforested forest (SF), were chosen to study heterotrophic respiration. All these study sites are adjacent to each other and situated within the same karst landscape. Three replicates from each land use areas were prepared. The SF site was established by the initiation of afforestation (tree plantation) in 2000. The SD site was developed by converting farmland in 2012. The main types of flora on the site of SD were red raspberry (*Rubus idaeus* L.), mulberry (*Broussonetia papyrifera* L.), *Asteraceae* spp., horse-weed (*Conyza canadensis* L.), *Xeridium sonchifoliumm*, *Viciae* spp. and *Ficus tikoua*. The main species in the SF site were Chinese mahogany (*Toona sinensis*), bamboo (*Neosinocalamus affinis*) and Chinese chest-nut (*Castanea mollissima*). The sloppy crop-land (SC) was under the cultivation of a corn (*Zea mays*)-rapeseed (*Brassica napus*) crops rotation. Corn was sown in April and, at full maturity, it was harvested (October). The sowing of rapeseed crop was carried out in November and reaped at maturity in March. Fertilization of N at the sloppy cropland was done at the dose of 368 kg N ha^{-1} yr^{-1}. At the cropland, the first fertilizer dose was applied on April 15, 2017 at the sowing time of corn during seedbed preparation. The second dose of fertilizer was applied as topdressing on May 22, and the third dose on June 13. The 4th fertilization was applied as top dressing on October 22 at rapeseed sowing time. Fertilizer was not applied on any other experimental land use type. The main characteristics of the study sites are shown in Table 1.

2.2. Measurement of soil heterotrophic respiration

Soil heterotrophic respiration was measured for six land use systems, in a time interval going from April 2017 to March 2018. For collection of gas samples and subsequent analysis, the static chamber–gas chromatography technique was used (Wu et al., 2018). Chambers were kept free from vegetation throughout the experiment and CO_2 emissions were solely released from soils. Throughout the experimental period, a stainless steel frame (square in shape: 0.50 m × 0.50 m = 0.25 m^2) was kept interleaved in the soil (at 0.20 m depth). In order to minimize eventual errors in data, three frames of the same size were inserted in each plot of the studied site. At the time of gas sample collection, a square chamber having the bottom area equal to that of the frame inserted into the soil (i.e. bottom area: 0.25 m^2) with 0.50 m height was placed on the frame. Two mini-fans (12 V D.C.) were fitted in the chamber to mix air and to create air turbulence.

Five samples were collected from the chamber to determine CO_2 fluxes. A 30 ml air-tight syringe was used to collect gas during a 40 min enclosure period. Soil CO_2 emissions were measured on weekly basis during the rainy season for each plot, whereas it was carried out every two weeks for the rest of seasons. Gas sampling time was fixed at 9:00–11:00 a.m. throughout the experiment. The collected samples were brought to the laboratory for the analysis of CO_2 concentrations. The CO_2 concentration was analyzed using a gas chromatograph (7890-A, Agilant Technologies, USA). The gas chromatograph was fitted with a flame ionization detector (FID) at 250 °C. The column temperature was stablished at 55 °C. The CO_2 emissions were quantified using the linear or nonlinear variations in concentrations during the enclosed period (Chen et al., 2020). The total soil CO_2 emissions were quantified by taking into account linear interpolation of two consecutive sampling events (Chen et al., 2020).

2.3. Ancillary measurements

The measurement of soil temperature and moisture was made at 5 cm depth on the same days of gas sampling. A mobile frequency domain reflector probe (R.D.S. Tech. Co. Ltd., Nan-jing, Jiangsu, China) was used to monitor soil moisture. Soil temperature was recorded using a thermometer (JM-624, Tian-jin Jin-ming Instrument Co. Ltd., Tian-jin, China). Water filled pore space (WFPS) was determined using the

Table 1
Some specific properties of the studied soils.

	pH	Total nitrogen (g kg^{-1})	Soil organic carbon (g kg^{-1})	Bulk density (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)
SC	7.67 (0.11)	2.59 (0.5)	23.22 (1.11)	1.26 (0.3)	65.20 (2.02)	11.94 (0.15)	22.86 (1.02)
NC	7.15 (0.23)	2.35 (0.3)	24.09 (1.14)	1.15 (0.2)	28.71 (1.89)	47.22 (0.21)	24.02 (1.02)
GD	6.64 (0.21)	2.03 (0.6)	22.06 (1.10)	1.08 (0.1)	49.37 (2.04)	26.11 (0.19)	24.49 (2.14)
SGD	6.40 (0.25)	2.18 (0.4)	22.48 (1.16)	1.17 (0.4)	29.16 (1.08)	53.80 (2.01)	16.99 (1.08)
SD	6.77 (0.27)	2.92 (0.7)	31.43 (1.13)	1.07 (0.3)	30.11 (1.45)	44.13 (1.97)	25.73 (1.16)
SF	6.99 (0.33)	3.88 (0.5)	40.76 (1.12)	1.05 (0.1)	26.91 (2.01)	52.50 (2.7)	20.60 (1.40)

SC: cropland site; NC: newly abandoned crop; GD: grassland; SGD: shrub and grassland; SD: shrubland; SF: forest. Values in parenthesis are standard errors of means (n = 3).

following formula (Chen et al., 2020):

$$WFPS(\%) : v / [1 - BD / 2.65)] \times 100\%$$

where BD denotes bulk density of soil (g/cm^3), and v is the volumetric water content in soil (cm^3).

The concentrations of nitrate (NO_3^--N), ammonium (NH_4^+-N), total dissolved nitrogen (TDN) and dissolved organic C (DOC) were analyzed every two weeks. From each plot, three soil subsamples (taken at 0–10 cm depth) were analyzed to determine NO_3^--N, NH_4^+-N, TDN, and DOC concentrations. A weight of 5 g soil was taken in a bottle. A volume of 25 ml 1 M potassium chloride (KCl) solution was added to soil and shaken on a mechanical shaker for 60 min at room temperature at 250 revolutions per minute (rpm). The mixture was filtered through Whatman filter paper no. 40. The extract was analyzed for mineral N on a flow injection analyzer (Skalar B–V Analytics., San, Netherlands) using a colorimetric method (Wu et al., 2018). For DOC and TDN determination, soil sample was mixed with deionized water (1:5, soil: solution/deionized water). After 60 min shaking, the mixture was centrifuge at 8000 rpm for 5 min. Supernatant was filtered through a membrane (0.45 μm) fitted at the tip of a plastic syringe. The DOC and TDN in the filtered extract were determined using a TOC analyzer (vario-max, Elemental Analyzer Instrument, Netherlands). Data on air pressure and temperature, and precipitation were obtained from the meteorological station installed besides the study sites.

2.4. Analysis of data

Data was analyzed using one-way Analysis of Variance (ANOVA) to assess the influence of land use systems, soil parameters and climatic variables on soil heterotrophic respiration. Least significant difference (LSD) test was employed to identify significant differences. Pearson's correlation analysis was performed to find out the possible linkage among the soil properties and the heterotrophic respiration. The data were tested for normality before analyses. The statistical analyses were executed using of SPSS software.

3. Results

3.1. Climate and soil variables

The average air temperature of the whole year and the annual precipitation were 17.1 °C and 1247 mm (Fig. 1). Soil temperature for the SC site varied from 2.8 to 30 °C, with mean value of 19.6 °C, for the SD site varied from 4.7 to 26.9 °C, with mean value of 17.6 °C, for the SF site went from 4.5 to 25.1 °C, with average value of 18 °C, for the NC site the range was 6.8–30.2 °C with average value of 19.3 °C, for the GD site 4.5–27.4 °C, with average value of 19.5 °C, and for the SGD site 6.3–28.5 °C, with average value of 18.7 °C. The soil moisture was measured as water filled pore space (WFPS), which varied from 16.4 to 75.7% (average: 53%) for the SD site, 11.8–91.6% (average: 57%) for the SC site, 26.89–72.65% (average: 56.65%) for the SF site, 22.6–73.9% (average: 49.8%) for the NC site, 36.2–72.5% (average: 58.7%) for the GD site, and 30.2–74.1% (mean: 55.3%) for the SGD site (Fig. 2). No significant ($p < 0.05$) effect of land use type was observed to affect soil moisture and temperature. The mean NH_4^+-N concentration for the SC site (4 mg N kg^{-1}) was considerably and significantly ($p < 0.05$) lesser than in all other sites (with the highest corresponding to SF: 12 mg N kg^{-1}) (Fig. 3). Similarly, the mean NO_3^--N concentration for the GD site (3.87 mg N kg^{-1}) was significantly ($p < 0.05$) greater than those in all the other sites under study (the highest was 88 mg N kg^{-1} for the SC site). The TDN concentration in the soil of the SD site (mean: 88 mg N kg^{-1}) was significantly ($p < 0.05$) higher than those in all the other studied sites (the highest was measured at the SC site: 185 mg N kg^{-1}). The mean value of DOC contents for the SF site (117 mg C kg^{-1}) was considerably and significantly ($p < 0.05$) higher than those in the other sites.

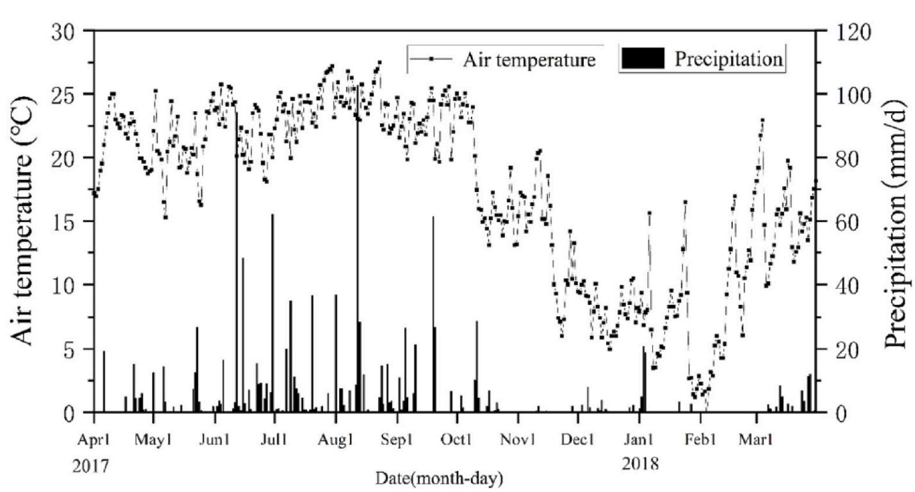

Fig. 1. Fluctuations of air temperature and precipitation in the study area from April 2017 to March 2018.

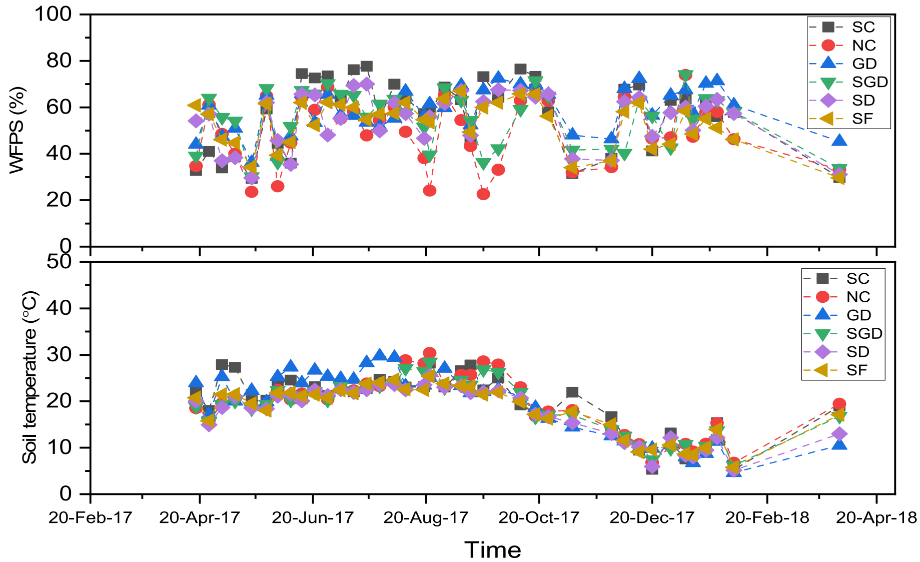

Fig. 2. Variations of water filled pore space and temperature in the different sites of the study. SC: cropland site; NC: newly abandoned crop; GD: grassland; SGD: shrub and grassland; SD: shrubland; SF: forest.

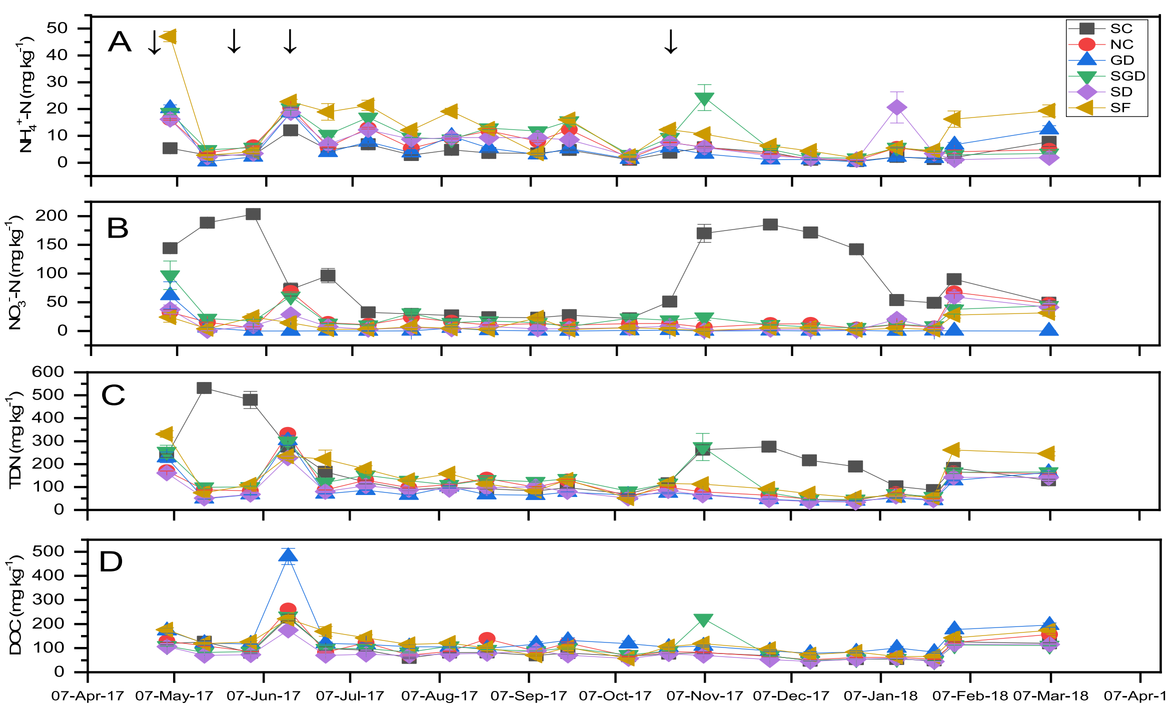

Fig. 3. Concentrations of NH_4^+-N (A), NO_3^--N (B), TDN (C) and DOC (D) in the soil of the different sites of the study. The arrows with downward direction denote the time of fertilizer application to the cropland plots. The vertical bars denote the standard errors of replicates (n = 3). SC: cropland site; NC: newly abandoned crop; GD: grassland; SGD: shrub and grassland; SD: shrubland; SF: forest.

3.2. *Soil heterotrophic respiration*

Soil heterotrophic respiration was significantly ($p < 0.05$) influenced by land use systems. Soil CO_2 emissions showed diverse patterns in the study sites. The values were: SC site: 3.82–191.51 mg C m^{-2} h^{-1}, NC site: 1.04–129.08 mg C m^{-2} h^{-1}, GD site: 3.59–100.77 mg C m^{-2} h^{-1}, SGD site: 0.30–393.56 mg C m^{-2} h^{-1}, SD site: 3.0–116.01 mg C m^{-2} h^{-1}, and SF site: 10.67–398.27 mg C m^{-2} h^{-1} (Fig. 4A). Highly significant and positive relationships between CO_2 emission and soil temperature were observed for all the studied land use types (Table 2). However, WFPS, NO_3^--N, NH_4^+-N, ETN and DOC concentrations showed a diverse pattern of positive and negative but non-significant correlations with soil CO_2 flux. The cumulative soil CO_2 fluxes for the studied sites were as follows: SC site: 5415.2 kg C ha^{-1}, NC site: 4019.9 kg C ha^{-1}, GD site: 2459 kg C ha^{-1}, SGD site: 5262 kg C ha^{-1}, SD: 2447.6 kg C ha^{-1} and SF site: 13597 kg C ha^{-1} (Fig. 4B).

4. Discussion

Soil heterotrophic respiration (RH) is imperative in context of climate change because of its sensitivity to soil C, climatic and environmental conditions. A variety of environmental, edaphic and biotic factors influence soil heterotrophic respiration (RH) in ecosystems (Ataka et al., 2020; Hu et al., 2018). Land use systems substantially

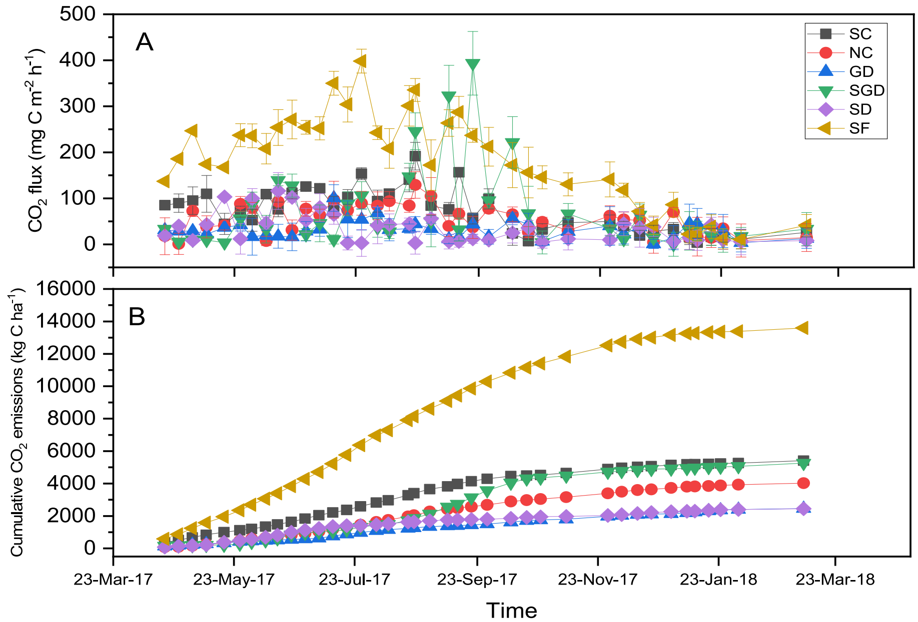

Fig. 4. Soil CO_2 fluxes from the different land use sites of the study. The vertical bars denote the standard errors (n = 3). SC: cropland site; NC: newly abandoned crop; GD: grassland; SGD: shrub and grassland; SD: shrubland; SF: forest.

Table 2
Pearson correlations between soil parameters and heterotrophic respiration of different land use sites.

Variables	SC	NC	GD	SGD	SD	SF
	Heterotrophic respiration					
Soil temperature	0.775**	0.617**	0.283**	0.535**	0.230**	0.858**
WFPS	0.013ns	0.004ns	0.029ns	−0.139ns	−0.041ns	0.310ns
NH_4^+-N	0.231ns	0.437ns	0.105ns	0.251ns	0.223ns	0.280ns
NO_3^--N	−0.325ns	−0.199ns	−0.032ns	−0.150ns	−0.088ns	−0.159ns
ETN	−0.215ns	0.174ns	−0.218ns	0.046ns	0.218ns	0.116ns
DOC	0.050ns	0.165ns	0.233ns	0.074ns	0.205ns	0.312*

WFPS: water filled pore space (%); DOC: dissolved organic carbon (mg kg^{-1}); ETN: extractable total nitrogen (mg kg^{-1}); SC: cropland site; NC: newly abandoned crop; GD: grassland; SGD: shrub and grassland; SD: shrubland; *: $p < 0.05$, **: $p < 0.01$; SF: forest; ns: not significant.

affect soil physicochemical characteristics, vegetation, and climate traits and ultimately heterotrophic respiration (Jian et al., 2022). Specifically, land use type is an important factor influencing heterotrophic respiration. In the present study, the results of heterotrophic respiration showed a diverse seasonal pattern over a year long period that was affected by various soil properties and climatic variables across six land use systems in a subtropical Karst landscape. The lowest RH occurred in the SD site (annual cumulative soil CO_2 flux: 2447 kg C ha^{-1}, almost equal to the GD site flux: 2459 kg C ha^{-1}) whereas the maximum RH corresponded to the SF site (annual cumulative soil CO_2 13597 kg C ha^{-1}). The order of RH flux from different land use systems was as follows: SD site < GD site < NC site < SGD site < SC site < SF site. The assorted seasonal pattern of RH across the studied land use systems can be elaborated by several ways. Soil characteristics and climate variables were the foremost drivers responsible for RH values in the present study. The linkage among these drivers and RH could be a plausible factor to explain RH variations in land use types. Specifically, soil temperature appeared as a key driver to explain heterotrophic respiration variability in all land use systems.

Temperature is a robust controller of changes in soil heterotrophic respiration (Moonis et al., 2021). Higher temperature stimulates soil RH by enhancing the activities of extracellular enzymes that disintegrate larger organic particles to smaller ones by improving the utilizing rates of solubilized substrates by microbes, and by accelerating microbial respiration (Sihi et al., 2018; Ye et al., 2019). According to the kinetic theory proposed by Arrhenius (1889), it is extensively presumed that microbial degradation of organic matter is increased with increase in temperature. Therefore, high temperature is expected to enhance heterotrophic respiration and induce drastic environmental effects on global warming by increasing CO_2 concentrations in the atmosphere. Numerous earlier studies reported positive relationships between RH and temperature (Butler et al., 2019; Delogu et al., 2017; Johnston and Sibly, 2018). In the summer season, RH greatly increased in response to increase of soil temperature, even at the events of high precipitation, where soil moisture was improbable to be restraining. The pronounced impact of temperature during the summer season was due to increased microbial biomasses or alteration in community structure and composition, which perhaps resulted from increased availability of substrates (such as DOC contents). Thus, results of the present study suggest that temperature can be a limiting variable for heterotrophic respiration.

Higher fluxes of heterotrophic respiration can also be explained by higher contents of DOC in the soil. Soil organic matter (SOM) in the soil of SF site at the onset of the study was also higher (Table 1). It is most likely that the mineralization of SOM provided substrates of readily available C (i.e. DOC) to soil microbes, and thus enhanced heterotrophic respiration (Bond-Lamberty et al., 2018). Heterotrophic respiration is the result of soil fauna and soil microbes decomposing plant litter and SOM. Higher activities and movement of microbes and small animals such as earthworms assist in breaking down larger particles of organic matter and litter fall, resulting in higher rates of heterotrophic respiration. Instead, if soil organic matter is protected in soil by physical or chemical processes, it is challenging to decay by microorganisms due to limited availability of appropriate substrate (Amelung et al., 2020).

Water filled pores space (WFPS), in other words soil water content, also markedly affected RH rates in all the studied sites. Heterotrophic respiration had positive correlations with WFPS, indicating that mineralization and liberation of DOC were facilitated, with the consequent of higher activities of soil microbes and, therefore, increased heterotrophic respiration (Yan et al., 2018). Soil moisture facilitated the highly labile DOC to be consumed by microbes, linking SOC pool with RH. Sheng et al. (2010) reported significant ($p < 0.01$) correlation between RH and soil moisture in soils of citrus orchards, woody forest, and sloppy land, but not in those where *Schima superba* and *Cunninghamia lanceolata* were growing. In the SF site of current study, WFPS had a positive and pronounced effect on heterotrophic respiration, which indicated that higher moisture contents enhanced heterotrophic respiration, plausible due to the acceleration of microbial activities through higher supply of readily available organic C. A global meta-analysis on heterotrophic respiration conducted by Liu et al. (2016) also reported that an increased heterotrophic respiration occurred due to the increased precipitation. It is reasonable that the modification of soil micro-environment and C return from litter fall caused higher RH fluxes in the SF site (Shi et al., 2020). Higher biomass production results in higher litter fall return, which are good source of C substrates for soil microorganisms (Chen et al., 2015; Fisk and Fahey, 2001), causing higher rates of RH. Although it is well established that higher DOC contents in soil stimulate the RH flux, some contradictory reports have also been presented in the literature. In that line, the finding that heterotrophic respiration showed negative correlation with SOC in a soil of Mosoo bamboo forest (Tang et al., 2016), whereas RH had positive correlation with SOC in temperate forest soils (Wang and Yang, 2007). This disparity in the response of RH fluxes to SOC contents might be due to site specific characteristics, not only because of SOC contents but also other edaphic and climatic factors. The data of the present study showed that RH highly correlated with soil temperature in all study sites, but more strongly in the SF site (Table 2). It is noteworthy to mention here that though the soil temperature was lower in the SF site than that of other sites, the RH flux was greater. This might be because of higher labile organic C contents which enhanced the RH rate.

Soil bulk density influences the microbial activities through controlling substrates, oxygen and water (Kaiser et al., 2015). Higher bulk density is associated to compaction of soil, lowering oxygen and water accessibility to microorganisms. Therefore, soil physical properties affect heterotrophic respiration primarily through affecting water movement, substrate availability and gas diffusion (Amelung et al., 2020). Soil bulk density of the SF site was the lowest and thus favored higher RH flux. Mineral N has also been documented to affect the soil RH (Chen et al., 2018). Generally, addition of N fertilizer to soil increases RH fluxes. According to this, higher RH flux was expected in the SC site as N fertilizer was applied at different intervals. Nevertheless, lower RH flux was observed in SC site than other sites where no additional N was added. Treseder (2008) reported some mechanisms pertinent to the negative impacts of N application on RH, including N toxicity (pH concerns or osmotic potential issues) and declining accessibility of C. Therefore, it could be supposed that lower RH flux in SC site than that of other sites was because of these reasons. However, we could not draw a solid conclusion about the relationship between the mineral N and RH in this study. Overall, the results of diverse pattern relationships (positive, negative, significant and non-significant) among RH and NH_4^+, NO_3^-, DOC and TDN in all land-use systems (Table 2) show that RH highly depends on several environmental factors.

5. Conclusion

Various soil and climatic factors were determined for the appraisal of soil heterotrophic respiration (RH) in Karst landscape soils. The lowest RH scores were found in the SD site (annual cumulative soil CO_2 flux: 2447 kg C ha^{-1}), whereas the maximum heterotrophic respiration occurred in the SF site (annual cumulative soil CO_2 13597 kg C ha^{-1}). The order of RH flux from the different land use systems was as follows: SD site < GD site < NC site < SGD site < SC site < SF site. The RH respiration significantly correlated with soil temperature, highlighting the most relevant driver for heterotrophic respiration. It is suggested that further research could focus on determining heterotrophic respiration rates for other systems, and specifically for those converted from other land use types.

Author contribution statement

Muhammad Shaaban analyzed data and wrote manuscript; Bing Ren, Ping Chen, Xiran Yang, Yuxing Chen, perceived the experiment; Zhengyou Zhang, Bin Chen, and Tao Peng analyzed samples of experiments; Avelino Núñez-Delgado revised and improved the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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