Soil Carbon Effluxes of Forest Ecosystems in China

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Abstract Forest soil is the largest carbon pool in terrestrial ecosystem, and the soil-to-atmosphere CO_2 flux (soil respiration, *Rs*) is the main link between soil and atmosphere. However, due to the lack of integration of field observations, substantial uncertainties exist in quantifying large-scale soil carbon effluxes, which limit our understanding of the fate of forest soil in a warming world. Here, China's forest ecosystems were divided into six forest types in six regions, and an integrated soil respiration database (N=634) was compiled to evaluate soil carbon effluxes by random sampling with replacement. Average annual *Rs* was 783 g C m^{-2} yr^{-1} across China, ranking from the highest to the lowest as follows: East, Southwest, South, Northwest, Northeast and North. Total soil carbon emissions were 1472.6 Tg C yr^{-1} in China's forest ecosystems, and about 69% from three southern regions (i.e., Southwest, Southern China and Eastern China) and 31% from three northern regions (i.e., Northwest, Northern China and Northeast). Evergreen needleleaf forest (529.09 Tg C yr^{-1}, 52%) and evergreen broadleaf forest (343.01 Tg C yr^{-1}, 34%) were the main source of soil carbon emissions in three southern regions, while deciduous broadleaf forest (334.36 Tg C yr^{-1}, 74%) was the main emissions in three northern regions. Our results provide a better understanding of the distribution and magnitude of soil carbon effluxes in China's forest ecosystems.

Keywords: Soil respiration, Carbon cycle, Spatial pattern, Forest type, Bamboo, China

1. Introduction

The soil-to-atmosphere flux of CO_2 generated by belowground autotrophic and heterotrophic processes, commonly termed soil respiration, represents an integrated response throughout the soil profile (Schlesinger & Andrews, 2000; Wei et al., 2014) and comprises the second-largest terrestrial carbon flux (Lei et al., 2021). Forest soil is recognized the largest carbon pool in terrestrial ecosystem (Post et al., 1982; Piao et al. 2009). The contribution of soil carbon effluxes in global forests to the terrestrial ecosystem had been roughly estimated to range from 32% (Warner et al., 2019) to 57% (Raich et al., 2002). Thus, forest soil respiration is an important part of terrestrial ecosystem and its accurate assessment will have a profound impact on global carbon balance. A better understanding of forest carbon cycle can provide a scientific basis for diplomatic negotiations on climate change and for the development of national carbon management policies (Deng et al., 2010; Fang et al., 2014; Pan et al., 2011; Yang et al., 2014).

Compared with vegetation biomass, soil carbon dynamics in forest ecosystems remain unclear (Pan et al., 2011). The uncertainties in soil carbon efflux estimation are largely caused by two aspects. First, year-round *Rs* measurements are expensive and sometimes difficulty to perform (Jian et al., 2020). Compared with estimation of terrestrial carbon fluxes such as gross primary production (GPP) and net primary production (NPP), the estimation of soil respiration is relative few (Hashimoto et al., 2015; Huang et al., 2020). Additionally, soil respiration has a high spatial heterogeneity, making it difficult to precisely estimate *Rs* at regional to continental scales (Bond-Lamberty & Thomson, 2010).

The rapid development of terrestrial carbon cycle research provides a new opportunity for accurate assessment of forest ecosystems (Yang et al., 2014). The use of the accumulated data for field observations will improve the large-scale estimates of soil respiration (Hashimoto et al., 2015). An early method frequently used to measure *Rs* was alkali absorption, which might underestimate *Rs* (Chen et al., 2008; Jian et al., 2020). But in recent decades, soil respiration measurements have become more and more standardized. The infrared gas analyzers (e.g., LI-6400, LI-8100, LI-8150) and gas chromatography gradually become the most popular methods *in situ* measurements (Sun et al., 2020), among which the methodological differences tend to be narrowed (Wang et al., 2011; Yang et al., 2018; Zheng et al., 2010).

China accounts for 5.4% of the world's forest area, ranking fifth in the world (FAO, 2020). Because of ecological restoration projects, its forest area has been increasing in recent decades (Fang et al., 2001; Liu et al., 2008). One recent study showed that southwest forest and northeast forest in China are becoming important land sink (Wang et al., 2020). In addition, China spans large geographic and climatic gradients, including a wide variety of boreal, temperate, subtropical and tropical forests (Fang et al., 2012; Jia et al., 2018). Different forest types and positions could experience different soil carbon processes (Liu et al., 2011). A wide range of studies focused on how big the carbon sink might be (Fang et al., 2007; Pan et al., 2011; Tian et al., 2011; Wang et al., 2020). Bond-Lamberty et al. (2018) and Naidu & Bagchi (2021) found that NPP may not compensate for rising soil heterotrophic respiration under climate change, and thus it is important to quantify soil carbon effluxes to accurately evaluate ecosystem carbon source/sink magnitude.

Different estimates of soil respiration in China's forest ecosystems have been made, and the mean annual *Rs* ranged from 745 g C m^{-2} yr^{-1} to 976 g C m^{-2} yr^{-1} (Table 1). However, the mean annual *Rs* values were averaged with the available samples (N=50–139) (Chen et al., 2008; Song et al., 2014; Zhan et al., 2012; Zheng et al, 2010), and the weights of different forest types and their distribution areas were seldom considered. Furthermore, the small sample sizes (N=50–139) and different measurement methods (e.g., various infrared gas analyzers, gas chromatography, alkali absorption method) used in these previous studies could increase the uncertainty of evaluating soil carbon effluxes in forest ecosystems at the national scale. Here, we developed a comprehensive and uniform database of *Rs* observations made in Chinese forest ecosystems through 2018 (N=634), and used it to quantify and analyze *Rs* patterns of different forest types across these large regions. This study thus provides a better understanding of forest soil respiration and in turn deepens our understanding of whole-ecosystem carbon balance in China.

2. Materials and methods

2.1. Study Area and Forest Types

China's forests are usually divided into six regions: Northwest (NW), Northern China (NC), Northeast (NE), Southwest (SW), Southern China (SC) and Eastern China (EC). Forests cover ~23% of the land area in China (State Forestry and Grassland Administration, 2019), mainly locate in SW, SC and NE (Figure1a, Table S1). The mean annual temperature (MAT) and mean annual precipitation (MAP) across the study sites ranged from -5.4 to 23.8 °C and 117 to 3000 mm, respectively (Figure1b). Five major forest types are usually classified across China based on the principles of Chinese vegetation regionalization (Dai et al., 2015; Yang et al., 2014; Zhang et al., 2014; Zheng et al., 2020), including evergreen broadleaf forest (EBF), deciduous broadleaf forest (DBF), evergreen needleleaf forest (ENF), deciduous needleleaf forest (DNF) and broadleaf and needleleaf mixed forest (MF). Bamboo forest (BF) was also taken into account in the recent studies on carbon budget of forest ecosystems in China (Song et al., 2014; Tan get al., 2018; Wang et al., 2018). Thus, this study included the above-mentioned six forest types. The area of each forest type was derived from China land cover in 2010 (Wang et al., 2018).

2.2. Data Collection

The terms "soil respiration", "soil carbon (or CO_2) efflux" or "soil carbon (or CO_2) emission" were searched from publications before 2018 in the China Knowledge Resource Integrated Database (http://www.cnki.net/), China Science and Technology Journal Database (http://www.cqvip.com), ScienceDirect (http://www.sciencedirect. com/), ISI Web of Science (http://isiknowledge.com/) and Springer Link (http://link.springer.com/). Furthermore, previous integrated global and regional forest soil respiration data, such as Chen et al. (2008), Chen et al. (2010), Chen et al. (2014), Song et al. (2014) and Jian et al. (2021a), were also checked to supplement our database.

The following criteria were used to ensure data consistency and accuracy: i) *Rs* was measured *in situ* with infrared gas analyzers (IRGA, model LI-6400, LI-8100, LI-8150) or gas chromatography (GC), which were the most popular methods in field experiments and provide methodological consistency (Zheng et al., 2010; Wang et al., 2011; Yang et al., 2018). ii) Forest stands with obvious disturbances (e.g., wildfire, cutting, intensive management, etc.) or manipulation experiments (e.g., fertilization, elevated carbon dioxide, litter removal or addition, etc.) were excluded. In global soil respiration database (SRDB-V5), China's forests with obvious disturbances and manipulation experiments accounted for about 5% and 30%, respectively (Jian et al., 2021a). iii) Data from forested swamps and commercial plantations (e.g., orchard, rubber, etc.) were not examined.

Based on these criteria, a total of 634 annual soil respiration observations was assembled from 349 published studies across China, including 97 study sites (Appendix S1). In addition, we recorded related information for each dataset, including geographical location (latitude, longitude and elevation) and climate factors (MAT and MAP).

2.3. Data Analyses

First, annual *Rs* data were converted to the same unit (g C m^{-2} yr^{-1}). Second, generalized linear model was used to test the differences among different forest types in the same region and among the same forest type in different regions. Third, total soil carbon effluxes of China's forest ecosystems were estimated using the following equation:

$$\mathrm{R_{Total}} = \sum_{k=1}^{k} \sum_{i=1}^{i} (R_{i,k} \times A_{i,k})$$

$\mathrm{R_{Total}}$ represented the total soil carbon effluxes, $\mathrm{A_{i,k}}$ was the area of each forest type in Region K, $\mathrm{R_{i,k}}$ was the average soil carbon efflux of each forest type in Region K, which was derived from random sampling 80% of annual *Rs* data in each forest type from the original dataset (N=634). Because of the small distribution area (~0.7% of total forest area), five forest types in different regions (i.e., EBF and MF in Northwest, DNF in Southwest, Southern and Eastern China) had not available annual *Rs* data, which were replaced by the average across the entire region. The random sampling with replacement was repeated 1000 times to calculate the total soil carbon emissions.

The effects of region, forest type and their interactions on annual *Rs* were tested with the generalized linear model (SPSS Statistics 21, SPSS Inc., Chicago, USA). Differences between means were compared using Bonferroni tests with a significance level of 0.05. Random sampling with replacement was performed using R software (R Core team 2019, version 4.0.2). The graphs were plotted in OriginPro (OriginLab Corporation, Northampton, MA, USA, Version 2021). The database in this study is available as supplementary material (Supplementary Data 2).

3. Results

3.1. Spatial Patterns of Annual *Rs* in China's Forests

Annual *Rs* of different forest types and their areas are the important indexes to calculate total soil carbon effluxes. The spatial distribution pattern of annual *Rs* in China's forest ecosystems decreased significantly with the increase of latitude from south to north, but there was no clear trend with longitude (Figure S1). A summary of the annual *Rs* dataset was listed in Table S1. The dataset included 634 samples, which mainly concentrated in EBF and ENF in Southern and Eastern China (~48%), but the largest region of Southwest only accounted for ~10%. The mean of the published annual *Rs* was 852 g C m^{-2} yr^{-1}, ranging from 260 to 2058 g C m^{-2} yr^{-1} (Table S1); the lowest annual *Rs* was from DBF in high-altitude Gongga Mountain (2875 m) in the Southwest region (Luo et al., 2012), and the highest from EBF in Southern China (Zhou et al., 2011).

The mean annual *Rs* from the observational studies varied widely from different forest types and regions in China (Table S1). The interaction between forest type and region was significant (Wald Chi-Square=77.730, P<0.001) (Table S2). EBF and BF are usually distributed in the southern three regions (i.e., Southwest, Southern China and Eastern China), and their mean annual *Rs* rates were the largest and the differences were not significant. The comparisons between evergreen and deciduous forests revealed that for southern broad-leaved forests, EBF was significantly larger than DBF (i.e., 936 vs. 284 g C m^{-2} yr^{-1}, $P<0.01$ in Southwest; 983 vs. 775 g C m^{-2} yr^{-1}, $P<0.01$ in Southern China; 1181 vs. 871 g C m^{-2} yr^{-1}, $P<0.05$ in Eastern China), but for northern coniferous forests, the differences were not significant between ENF and DNF (i.e., 652 vs. 622 g C m^{-2} yr^{-1}, $P=0.83$ in Northwest; 694 vs. 618 g C m^{-2} yr^{-1}, $P=1.00$ in Northern China; 527 vs. 576 g C m^{-2} yr^{-1}, $P=0.60$ in Northeast). Broad-leaved forests usually had larger mean fluxes than the coniferous forests, the differences were significant in Southern and Eastern China (EBF vs. ENF) and in Northeast (DBF vs. DNF), but not significant in Southwest (EBF vs. ENF) and in Northwest and Northern China (DBF vs. DNF).

DNF is mainly distributed in the northern three regions (i.e., Northwest, Northern China and Northeast), and their differences of annual *Rs* were not significant. The average annual *Rs* rates of DBF were similar in Northeast, Northwest, Southern and Eastern China, ranging from 710 g C m^{-2} yr^{-1} to 871 g C m^{-2} yr^{-1}, significantly larger than that of DBF from high-altitude Gongga Mountain in Southwest (284 g C m^{-2} yr^{-1}). The annual *Rs* of six forest types were usually the largest in Eastern China, except for higher ENF in Southwest (848 g C m^{-2} yr^{-1}) than in Eastern China (774 g C m^{-2} yr^{-1}), but their difference was not significant.

3.2. Total Soil Carbon Emissions and Their Distributions in China's Forests

Total soil carbon emissions from the random sampling with replacement were 1472.6 Tg C yr^{-1} in China's forest ecosystems (Figure 2). The largest emissions occurred in Southwest (415.8 Tg C yr^{-1}, 28%), followed by Southern China (330.2 Tg C yr^{-1}, 22%), both of which accounted for about half of China's forest soil carbon emissions. By contrast, only 80.6 Tg C yr^{-1} (5%) was released from Northwest. Geographically, total soil carbon emissions were relatively low across the three northern regions (80.6–232.9 Tg C yr^{-1}), and significantly higher in three southern regions (274.0–415.8 Tg C yr^{-1}), accounting for about 31% and 69% of national forest soil carbon emissions, respectively.

The amount of soil carbon emissions showed large differences among six forest types (Figure 2). DBF was the main source of soil carbon emissions (334.36 Tg C yr^{-1}, 74%) in three northern regions. ENF (529.09 Tg C yr^{-1}, 52%) and EBF (343.01 Tg C yr^{-1}, 34%) were the main emissions in three southern regions. The absence of available annual *Rs* from DNF in Southwest, Southern and Eastern China, as well as EBF and MF in Northwest, affected 0.7% of total forest area in China (Table S1). When the average values of the corresponding regions were substituted for the unavailable annual *Rs*, total soil carbon emissions in China's forests increased by only 0.4%.

3.3. Uncertainty Analyses of Total Soil Carbon Emissions

The data of each forest type among six regions was randomly sampled 1000 times, and 1.5 times interquartile range for each region was: 68.2–93.1 Tg C yr^{-1} (NW), 123.6–154.6 Tg C yr^{-1} (NC), 208.0–260.7 Tg C yr^{-1} (NE), 375.1–456.0 Tg C yr^{-1} (SW), 308.5–352.1 Tg C yr^{-1} (SC), 258.1–290.2 Tg C yr^{-1} (EC) (Figure 3). Southwest showed the largest variation, followed by Northeast and Southern China. Averaged total soil carbon emissions in the resampled data group were 1472.6 Tg C yr^{-1}. The maximum probability value was in 1455–1495 Tg C yr^{-1}, taking up 73% of the 1000 iterations (Figure 3). Compared with the directly summed soil carbon emissions of 1478.5 Tg C yr^{-1} (Table S1), i.e., the annual soil respiration rates of each forest type in six regions were averaged to sum the regional and national soil carbon effluxes, the difference was 5.9 Tg C yr^{-1}.

4. Discussion

4.1. Annual *Rs* in China's Forest Ecosystems

Annual *Rs* in China's forest ecosystems showed a significant latitudinal pattern, decreasing with increasing latitude (Figure S1). A similar pattern was also found for ecosystem respiration in China (Yu et al., 2013). Forests in China's Southern region experience relatively higher temperature and precipitation than do those in the northern region (Jiang et al., 2014). These differences may be the main reason affecting the soil respiration rate (Jian et al., 2021b; Rey et al., 2002).

The overall mean of *Rs* was 852 g C m^{-2} yr^{-1} in China's forests, in the range of the published studies (745–976 g C m^{-2} yr^{-1}, see in Table 1). The samples of annual *Rs* in the previous studies ranged from 50 to 139. The largest samples of 139 included shrub (Song et al., 2014). In contrast, the sample size was further extended and amounted to 634 in this study, covering 97 forest study sites, and included bamboo forests, which exhibited higher soil respiration rates (Table S1). This larger sample size and broader regional representation could help to improve the estimation accuracy (Chen et al., 2012). The average annual *Rs* in China's forests was 783 g C m^{-2} yr^{-1} when the total soil carbon emissions divided by forest area in this study (Table 1). The result was higher than 539 g C m^{-2} yr^{-1} from Yu et al. (2010) and 618 g C m^{-2} yr^{-1} from Jian et al. (2021b), who estimated annual *Rs* of China's forest ecosystems with the fitted models on the basis of monthly data.

Soil respiration rates in broad-leaved forests are usually larger than those in coniferous forests (Burton et al., 2002; Dai et al., 2015; Hudgens & Yavitt, 1997; Zhou et al., 2013). Similar results were also found in the present study, the average annual *Rs* in broad-leaved and coniferous forests were 796 g C m^{-2} yr^{-1} and 663 g C m^{-2} yr^{-1} at the national scale, respectively (Table S1). For evergreen forests, the differences were significant between EBF and ENF in Southern China (983 g C m^{-2} yr^{-1} vs. 654 g C m^{-2} yr^{-1}) and Eastern China (1181 g C m^{-2} yr^{-1} vs. 774 g C m^{-2} yr^{-1}), but for deciduous forests only between DBF and DNF in Northeast (710 g C m^{-2} yr^{-1} vs. 576 g C m^{-2} yr^{-1}). Vegetation can affect carbon emission rate by influencing soil microenvironment, soil structure, mass of debris in soil, and root respiration rate (Liu & Han, 2009; Raich & Tufekcioglu, 2000). Soil organic matter content of broad-leaved forest is higher than that of coniferous forest (Dai et al., 2015). In addition, broad-leaved forest has a higher turnover rate than coniferous forest (Olsson et al., 2012; Zheng et al., 2020). Therefore, in similar hydrothermal conditions, the soil respiration rates of broad-leaved forests are usually greater than those of coniferous forest.

4.2. Total Soil Carbon Emissions in China's Forest Ecosystems

The estimated forest soil carbon effluxes in China were 1473 Tg C yr^{-1}, which was higher than 820 Tg C yr^{-1} (Yu et al., 2010) and 1080 Tg C yr^{-1} (Jian et al., 2021b) (Table 1). Forest area increased rapidly in recent decades (Tang et al., 2018; Wu et al., 2014; Zhang et al., 2014). The larger forest soil carbon effluxes reported here partly resulted from the increases in forest areas. Compared with 152.2×10^4 km^2 of Yu et al. (2010) at 1 km spatial resolution in 1992-1993 and 174.9×10^4 km^2 of Jian et al. (2021b) at 0.5° longitude by 0.5° latitude in 1961-2014, the area of 188.2×10^4 km^2 in this study from China land cover in 2010 at 30 m spatial resolution (Wang et al., 2018) was increased by 24% and 8%, respectively (Table 1). Additionally, for the first time this study included bamboo forests, which is an important forest resource in three southern regions in China and the area is increasing year by year (Song et al., 2017; Zhou & Jiang, 2004). Bamboo exhibited higher soil emission rates (Table S1), thus, taking bamboo forests into account could improve the accuracy of soil carbon emissions of China's forests.

Among the six regions, Southwest experienced the largest soil carbon emissions (415.8 Tg C yr^{-1}), followed by Southern China (330.2 Tg C yr^{-1}). In contrast, Northwest showed the lowest emissions (80.6 Tg C yr^{-1}). Wang et al. (2018)

calculated vegetation, soil and total carbon stock for six regions in China's forest ecosystems. The regional pattern of soil carbon emissions was more closely related to vegetation carbon stock (R^2=0.89) rather than to soil carbon stock (R^2=0.39) in China's forest ecosystems (Figure 4). The difference was driven by northeastern China, which had high soil carbon storage (5025 Tg C) but low soil carbon emissions (only about half of the Southwest region). This phenomenon may be explained by the composition of soil respiration itself. As the second-largest terrestrial carbon flux, it mainly composed of autotrophic respiration (root respiration and rhizosphere microbial respiration) and heterotrophic respiration (microbial and soil animal respiration) (Bond-Lamberty et al., 2004; Schindlbacher et al., 2009). Temperature can affect plant growth and physiological activities to enhance root respiration. Moreover, temperature can regulate the activity of soil microorganisms, thus accelerating the decomposition of soil organic matter (Liu et al., 2002; Tjoelker et al., 2018). The northeast part of China belongs to the middle and high latitudes, and its frequent low temperatures likely inhibit *Rs*.

4.3. The Uncertainty of Soil Carbon Effluxes Estimation in China's Forests

Averaged soil carbon emissions from 1000 random samplings were 1472.6 Tg C yr^{-1} in China's forest ecosystems, and the maximum probability (73%) was in 1455–1495 Tg C yr^{-1} (Figure 3). The factors that may influence the results of this study were mainly as follows: i) Although the different forest types in each region were considered, the location (e.g., altitude, aspect, etc.) was neglected, the same weight was given to each observation point at the regional scale, which may affect the accuracy of the regional and national results. ii) The study sites were distributed unevenly, with ~36% of the observations concentrated in the seven ChinaFLUX sites and long-term ecological stations, i.e., Dinghushan (N=64), Maoershan (N=60), Tianjiling (N=28), Qianyanzhou (N=21), Baotianman (N=18), Dagangshan (N=18) and Changbaishan (N=17), while observations in other locations were relatively few. The sparse observations increase the uncertainties in evaluating large-scale carbon fluxes (Schimel et al., 2015; Xu & Shang, 2016). iii) Temperature and precipitation are the dominant controlling factors of *Rs*. High *Rs* values usually occur in areas that show a greater degree of synchronicity in the timing of their optimal temperature and moisture conditions (Bond-Lamterty & Thomson, 2010; Luo & Zhou, 2006; Wen et al., 2018; Yu et al., 2010). Additionally, seasonality (e.g., growing and non-growing season, wet and dry season) is also influence soil carbon emissions. However, it should be noted that the estimation of total soil carbon effluxes in the current study based on random selection with replacement, is lack of the mechanistic basis. Therefore, it needs model and space-based techniques to reduce spatial sampling bias and improve the accuracy in future studies.

5. Conclusions

In this study, we collected *in situ* annual soil respiration measurements with common infrared gas analyzers or gas chromatography to quantify the total soil carbon emissions and their spatial distributions in China's forests. Annual *Rs* decreased with the increase of latitude on the national scale, ranging from 260 to 2058 g C m^{-2} yr^{-1}. Total soil carbon effluxes were 1472.6 Tg C yr^{-1} in China's forest ecosystems. Southwest (415.8 Tg C yr^{-1}) and Southern China (330.2 Tg C yr^{-1}) experienced the largest soil carbon emissions, occupying about one half of the whole country. In terms of forest types, soil carbon emissions were mainly from evergreen needleleaf forest and evergreen broadleaf forest (~86%) in three southern regions, and mainly from deciduous broadleaf forest (~74%) in three northern regions. We supplemented the annual measurements of bamboo for the first time to evaluate soil carbon emissions in China's forests, accounting for about 3%. It is worth noting that bamboo forests are an unneglectable part due to their higher soil respiration rates and faster increasing areas. Our finding can provide a scientific basis for evaluating soil carbon effluxes among different forest types and regions in China.

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Figure 1. Geographic and climatic distributions of study sites. (a) The measurement sites across China's forests. The size and color of the circles represent the samples and forest types, respectively. (b) The study sites cover a wide range of mean annual temperature and mean annual precipitation. NW: Northwest, NC: Northern China, NE: Northeast, SW: Southwest, SC: Southern China and EC: Eastern China. Forests in Hong Kong, Macao, Taiwan and the South China Sea Islands were not included in the current study.

Figure 2. Soil carbon effluxes from different forest types in six regions. The error bar is standard deviation. The values in brackets are the regional soil carbon emissions and their percentages. EBF: evergreen broadleaf forest, DBF: deciduous broadleaf forest, ENF: evergreen needleleaf forest, DNF: deciduous needleleaf forest, MF: broadleaf and needleleaf mixed forest and BF: Bamboo forest.

Figure 3. Frequency distribution of soil carbon effluxes across China's forest ecosystems and the boxplot for six regions from the random sampling 1000 times with replacement. IQR: interquartile range. Region abbreviations are as in Figure 1.

Figure 4. Relationships between soil carbon efflux and carbon stock for six regions (NW, NC, NE, SW, SC and EC) in China's forest ecosystems. Region abbreviations are listed in Figure 1. Data of forest carbon stock from Wang et al. (2018).

Table 1. Comparisons of soil carbon effluxes in China's forest ecosystems

Annual Rs[a] (g C m^{-2} yr^{-1})	Total Rs (Tg C yr^{-1})	Total area (10^4 km^2)	Sample[b]	Method[c]	Bamboo[d]	Reference
	NA	NA	(Ann)	$IRGA_C$, $IRGA_O$, GC, AA	No	Chen et al., 2008
	NA	NA	(Ann)	$IRGA_C$, $IRGA_O$, GC	No	Zheng et al, 2010
	NA	NA	(Ann)	$IRGA_C$, $IRGA_O$, GC	No	Zhan et al., 2012
	NA	NA	(Ann)	$IRGA_C$, $IRGA_O$, GC, AA	Yes	Song et al., 2014
(539)			(Mon)	$IRGA_C$, $IRGA_O$, GC	No	Yu et al., 2010
(618)			(Mon)	$IRGA_C$, $IRGA_O$, GC, AA	No	Jian et al., 2021b
(783)			(Ann)	$IRGA_C$, GC	Yes	This study

a. Mean annual soil carbon effluxes, in brackets are mean values based on total forest area.

b. Ann: annual values, Mon: monthly values.

c. AA: alkali absorption method; GC: gas chromatography; $IRGA_C$: common infrared gas analyzers, i.e., LI-6400, LI-8100, LI-8150; $IRGA_O$: other infrared gas analyzers, e.g., LI-6200, LI-820, CI-310, PDA-100, GXH-305, CID-301PS, etc.

d. Bamboo forest was included or not.

NA: Not available.