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Original Research Article

Fine root turnover law and influencing factors in forest ecosystem

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ABSTRACT

Root turnover is a key process of terrestrial ecosystem carbon cycle, which is of great significance to the study of soil carbon pool changes and global climate change. However, because there are many measurement and calculation methods of root turnover, the results obtained by different methods are quite different, and the current research on root turnover of forest ecosystem on the global regional scale is not sufficient, so the change law of root turnover of global forest ecosystem is still unclear. By collecting literature data and unifying the calculation method of turnover rate, this study integrates the spatial pattern of fine root turnover of five forest types in the world, and obtains the factors affecting fine root turnover of forest ecosystem in combination with soil physical and chemical properties and climate data. The results showed that there were significant differences in fine root turnover rate among different forest types, and it gradually decreased with the increase of latitude; the turnover rate of fine roots in forest ecosystem is positively correlated with annual average temperature and annual average precipitation; fine root turnover rate of forest ecosystem is positively correlated with soil organic carbon content, but negatively correlated with soil pH value. This study provides a scientific basis for revealing the law and mechanism of fine root turnover in forest ecosystem.

Keywords: Fine Root Turnover; Global Forest Scale; Climate Factors; Soil Properties

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1. Introduction

Global warming has become a well-known fact. Over the past century, the average temperature of the earth's surface has increased by (0.6 ± 0.2) °C in the 20th century, and it is expected to continue to rise by 1.4–5.8 °C by the end of the 21st century. At the same time, the concentration of carbon dioxide (CO_2) in the atmosphere has also increased by 30%[1]. Ecosystem carbon cycle plays an extremely important role in regulating global climate change. Therefore, studying the carbon cycle law of various ecosystems is of great significance to explore the response to global change. The terrestrial ecosystem provides a "climate ecosystem" positive feedback enhancement region in the context of global warming[2], making the terrestrial carbon pool and carbon cycle the center of global carbon cycle change. Ecosystem soil organic carbon is the core of the distribution, migration and transformation of organic carbon in terrestrial ecosystems, and the input of soil organic carbon mainly comes from litter, root turnover and root exudates[3]. Root turnover is an important link in the carbon distribution process of terrestrial ecosystems. The survival and turnover of roots are of great significance to the carbon cycle of global ecosystems and global climate change.

Root system is an important organ of plant, which can absorb water and nutrients from the soil, which is very important for plant growth and adaptation to the environment. At the same time, the apoptosis and decomposition of root system can return nutrients to the soil, and it is an important source of soil organic matter[4–6]. Fine roots usually refer to roots with a diameter of less than 2 mm[3,7]. They have no xylem, small diameter, short life span, short cycle, large absorption surface area and strong physiological activity. They have a higher turnover rate than coarse roots. They are an important source of soil carbon and nutrients[8]. Although the fine root biomass accounts for only 3%–30% of the underground biomass of the forest ecosystem[9], it contributes 33%–67% of the production[10]. Root turnover refers to the generation and growth of new roots and the death and decomposition of old roots[11]. Arthur and Fahey[12] showed that the turnover of fine roots into soil organic matter is 1 to several times that of aboveground litter, indicating that fine root turnover plays an important role in soil organic carbon input. Li[13] found that the amount of nitrogen (N) returned by fine root death and decomposition to soil is greater than that of litter, while the amount of phosphorus (P) and magnesium (Mg) returned is equal to or slightly lower than that of litter, indicating that the nutrients that fine root turnover enters the soil are also an important source of maintaining soil fertility and soil organic matter. If fine root turnover is ignored, the evaluation of soil fertility will be far lower than its actual value, and the turnover of soil organic matter and nutrient elements will be underestimated by 20%–80%[14]. Liu[15] studied the fine roots of mangroves and found that the contribution rate of fine roots accounted for 92.4%–97.5% of the organic matter that plants input into the soil through litter every year. In addition, root turnover is highly sensitive to some factors leading to global change (such as temperature rise, CO_2 concentration rise, land cover pattern and precipitation pattern change)[8]. Therefore, understanding fine root turnover can provide theoretical basis and better ideas for further study of terrestrial ecosystem carbon cycle and analysis of global change pattern.

Forest is the main body of terrestrial ecosystem, and also the largest, most complex, multi species, multi-function and multi benefit ecosystem on land. It plays an indispensable role in ensuring the ecological security of land, improving the ecological environment, maintaining the ecological balance between man and biosphere, and maintaining biodiversity. The study of fine root turnover in typical forests in different climatic zones is of great significance to reveal the mechanism of material circulation and energy flow in forest ecosystems. At present, the research on fine root turnover in forest ecosystems mainly focuses on the seasonal changes of an ecosystem and environmental factors[16–18], and there are few studies on fine root turnover in forest ecosystems on a global scale.

There are many methods to measure fine root turnover in forest ecosystems, and many methods to estimate fine root turnover in terrestrial ecosystems have been produced in the past few decades[19,20]. Nowadays, commonly used methods include soil coring methods[21–23], ingrowth coring methods[24,25], minirhizotron methods[26–28] C and N budget methods[19] and isotope ^{14}C and ^{13}C methods[21,29]. Among them, the root drilling method is the earliest method used[21,22], and it is also the most commonly used method to study root biomass, productivity and turnover[30]. The advantage of this method is that it can estimate root yield relatively easily and quickly, and obtain more accurate root biomass data at the same time[3], which has obvious advantages in some studies that need specific biomass or productivity. Brunner *et al.*[31] compared and analyzed different methods of measuring fine root turnover, and found that in some shallow soils, soils with high sand and gravel content and steep slopes, the results obtained by using the root drilling method are more accurate and comparable. However, the root drilling method requires continuous measurement for many times, with heavy workload, time-consuming and laborious, and the peak or trough of root biomass may be missed when sampling[3]. Because the root drilling method needs to take the difference when calculating, some studies believe that this method is only applicable to plant roots with large fluctuations in fine root biomass[31]. The results of fine root biomass and turnover rate obtained by different measurement and calculation methods are also different[3,30,31]. For example, Wu *et al.*[30] used different methods to measure and calculate fine root biomass and turnover, and the results were quite different. Therefore, if the calculation methods of fine root biomass and turnover rate are not unified, the fine root data studied by different experts cannot be compared and analyzed, and the relationship between fine root turnover and the factors affecting fine root turnover on a larger spatial scale cannot be further compared. In order to use the results of previous studies to analyze the fine root turnover of forest ecosystems on a global scale, this study unified the calculation method of fine root turnover rate, and the unified fine root turnover rate can be directly compared. In addition, by collecting and analyzing the data of published literature, this paper studies the relationship between fine root turnover in forest ecosystem and the physical and chemical properties of climate and soil, hoping to provide a scientific basis for revealing the law and mechanism of fine root turnover in forest ecosystem, and provide data support for the study of terrestrial ecosystem carbon cycle and global climate change.

2. Materials and methods

2.1 Data screening criteria

In order to avoid the difference of turnover rate measured by different methods, the biomass method was used to calculate the fine root turnover rate (unit: a^{-1}) = underground net primary productivity (BNPP)/mean fine root biomass (B_{mean})[32], where BNPP = maximum fine root biomass − minimum fine root biomass[19]). If the calculation method of fine root turnover in the literature is consistent with this method, it should be adopted; if the data in the literature is different from the calculation method of fine root turnover rate in this study, the seasonal change data of forest fine root biomass provided in the literature should be recorded, the maximum and minimum values of annual biomass should be extracted to calculate BNPP, and then the fine root turnover rate should be calculated according to the above formula.

2.2 Data collection

Root turnover rate data are mainly from published journal papers and monographs. On the Web of Science (http://www.isiknowledge.com/) and CNKI database (http://www.cnki.net/) input keywords such as fine root turnover, forest and seasonal change for retrieval. 70 sets of data were obtained from 71 literatures published between 1981 and 2016, of which 44 were located in Asia, and 16, 7, 2 and 1 were located in North America, Europe, South America and Africa respectively. Record the location, longitude and latitude, altitude, annual average temperature (MAT), annual mean precipitation (MAP), vegetation type and vegetation composition of the sample plot. The missing longitude and latitude data are searched on Google Earth using the location information in the literature. The missing annual average temperature and precipitation information are extracted from the World Meteorological Database (www.worldclim.org) according to the location information of sample plots in the literature. If there are multiple literatures studying the fine root turnover of forests in the same location, or a literature studying the fine root turnover of different types of forests in the same location, the turnover rate data will be averaged.

If the data in the literature is presented in the form of charts, then through Engauge_Digitizer_(http://engauge-digitizer.soft112.com/) graphics digitization software extraction. The specific data extraction process is as follows: (1) import the target curve; (2) fix the coordinate axis, click at the origin of the coordinate axis, the maximum value of the X axis and the maximum value of the Y axis respectively, and enter the coordinate value of this point in the pop-up dialog box; (3) select the required data points on the target curve with the mouse; (4) record the data of the selected point. The data of soil physical and chemical properties are all from topsoil (0–30 cm). Soil pH value, soil bulk density, soil organic carbon content, soil cation exchange capacity (CEC), sandy soil content, loam content and clay content, according to the longitude and latitude data of sample points, in

HWSD V1.2 (Harmonized World Soil Database version 1.2) (http://www.iiasa.ac.At/Research/LUC/luc07/External-World-soil-database/TML/index.html?sb=1). In addition, MAT and MAP data lacking in data points are also obtained.

2.3 Data processing

The statistical software SPSS (IBM SPSS Statistics 19) was used to test the normality of the data distribution. The fine root turnover data did not conform to the normal distribution. The logarithm value of the data based on 10 was taken, and the logarithm value conformed to the normal distribution. Pearson analysis method in SPSS software was used to analyze the correlation between fine root turnover rate and climatic factors and soil physical and chemical properties.

Import the x-axis value (climatic factor and soil physical and chemical property data) and y-axis value (fine root turnover data after logarithmic value) into Origin (OriginLab Origin Pro v9.0.0b45) mapping software, draw a scatter diagram, and conduct linear regression analysis to obtain the univariate function relationship between climatic factor and soil physical and chemical property data and lg (fine root turnover) and R^2 value.

Division standard of forest climate zone: first, according to the approximate latitude range of tropical, subtropical, warm temperate, temperate and cold temperate zones, tropical forests are 0°–23°19'48", subtropical forests are 23°19'48"–30°, warm temperate forests are 30°–35°, temperate forests are 35°–45°, and cold temperate forests are ≥45°; then, according to the species composition and vegetation types of the sample plots at the edge latitude of each temperature zone, the sample plots at the edge latitude are subdivided. The reclassification standard is tropical: tropical rain forest, subtropical zone: evergreen broad-leaved forest, warm temperate zone: deciduous broad-leaved forest, temperate zone: coniferous and broad-leaved mixed forest, cold temperate zone: deciduous coniferous forest. After the above two standards are divided, the data of tropical forests, subtropical forests, warm temperate forests, temperate forests and cold temperate forests are 11, 9, 13, 30 and 7 respectively. Single factor analysis of variance in SPSS software was used to test the difference between the fine root turnover rates of the above five different zonal forests, and Duncan multiple comparisons were used for analysis.

3. Results and discussion

3.1 Spatial distribution of fine root turnover in forest ecosystem

The latitude distribution range of the surveyed sample plots is between 3°4'1"S and 62°46'59"N, including Asia, Africa, Europe, South America and North America (**Table 1**). Among them, 44 samples located in Asia are mainly distributed in East Asia, such as China and Japan, and a small number are located in southern India and Central Asia; most of the samples (16) located in North America are distributed on the east coast of North America, and the rest are distributed on the west coast and Canada in the north of North America; the sample points (7) located in Europe are mostly distributed along the west coast; the sample sites (2) located in South America are all in Brazil; Africa has the least sample point, only one, located in Côte d'Ivoire in the west of the African continent. There is a very significant negative correlation between the fine root turnover rate of forest ecosystem and the latitude gradient ($P < 0.01$), that is, the fine root turnover rat e gradually decreases with the increase of latitude (**Figure 1**).

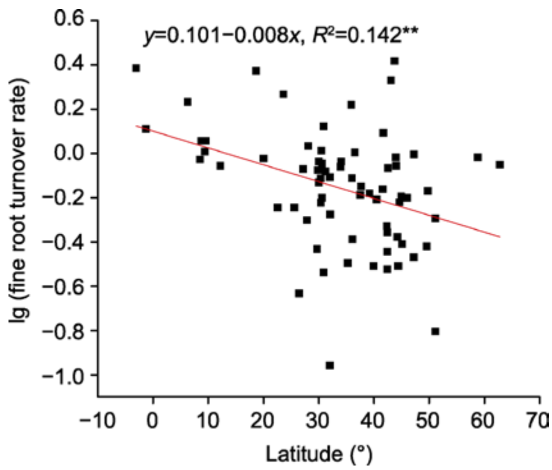

Figure 1. Patterns of fine root turnover rate in forest eco-systems with latitude.
** indicates significant correlation at the 0.01 level.

Table 1. Distribution of study sites

Plot	Continent	Country	Longitude and latitude	Plot	Continent	Country	Longitude and latitude
1	Asia	India	77°15'E, 8°28'59"N	36	Asia	China	128°5'40.56"E, 42°23'57.48"N
2	Asia	India	76°49'59"E, 9°22'1"N	37	Asia	China	128°4'59.88"E, 42°24'N
3	Asia	India	77°25'58.8"E, 9°31'58.8"N	38	Asia	China	128°6'29.16"E, 42°25'15.24"N
4	Asia	India	79°55'1.2"E, 12°10'58.8"N	39	Asia	China	128°30'E, 43°4'58.8"N
5	Asia	China	110°31'19.2"E, 20°1'1.2"N	40	Asia	China	127°31'48"E, 44°22'48"N
6	Asia	China	112°49'58.8"E, 22°34'1.2"N	41	Asia	China	88°13'48"E, 44°37'12"N
7	Asia	China	117°18'E, 23°35'24"N	42	Asia	Japan	142°6'E, 45°3'N
8	Asia	India	91°55'58.8"E, 25°34'1.2"N	43	Asia	China	128°53'13.2"E, 47°10'51.6"N
9	Asia	China	117°57'E, 26°28'1.2"N	44	Asia	China	127°54'36"E, 47°13'48"N
10	Asia	China	110°7'58.8"E, 27°9'N	45	North America	Panama	82°15'W, 8°45'N
11	Asia	China	119°10'48"E, 27°52'12"N	46	North America	Puerto Rico	65°49'1.2"W, 18°40'1.2"N
12	Asia	China	113°1'48"E, 28°7'12"N	47	North America	USA	84°30'W, 31°15'N
13	Asia	China	91°19'58.8"E, 29°40'1.2"N	48	North America	USA	92°W, 32°N
14	Asia	China	121°46'58.8"E, 29°48'N	49	North America	USA	111°45'W, 35°16'1.2"N
15	Asia	China	103°25'1.2"E, 29°58'58.8"N	50	North America	USA	76°27'43.2"W, 36°31'58.8"N
16	Asia	China	102°48'E, 30°1'1.2"N	51	North America	USA	82°22'1.2"W, 39°10'58.8"N
17	Asia	China	117°24'E, 30°22'12"N	52	North America	USA	78°45'57.6"W, 41°35'52.8"N
18	Asia	China	117°43'48"E, 30°22'48"N	53	North America	USA	72°11'24"W, 42°31'51.6"N
19	Asia	India	79°56'24"E, 30°28'58.8"N	54	North America	USA	71°45'W, 43°55'58.8"N
20	Asia	China	117°53'24"E, 30°34'48"N	55	North America	USA	72°13'1.2"W, 44°N
21	Asia	China	117°54'E, 30°34'48"N	56	North America	USA	122°13'1.2"W, 44°13'58.8"N
22	Asia	China	121°54'25.2"E, 30°52'55.2"N	57	North America	USA	121°34'1.2"W, 44°25'58.8"N
23	Asia	India	75°40'12"E, 30°54'N	58	North America	USA	68°41'6"W, 44°55'19.2"N
24	Asia	China	119°13'58.8"E, 31°58'58.8"N	59	North America	USA	122°W, 46°N
25	Asia	Japan	131°12'E, 32°3'N	60	North America	Canada	89°28'58.8"W, 49°32'24"N
26	Asia	China	108°7'58.8"E, 33°58'1.2"N	61	Europe	Italy	14°33'E, 41°43'1.2"N
27	Asia	Japan	135°37'1.2"E, 34°4'58.8"N	62	Europe	France	3°49'4.8"E, 43°41'16.8"N
28	Asia	China	116°49'58.8"E, 35°52'58.8"N	63	Europe	France	4°37'48"E, 49°45'36"N
29	Asia	Japan	104°7'55.2"E, 36°N	64	Europe	Germany	10°26'2.4"E, 51°4'48"N
30	Asia	Japan	140°13'1.2"E, 36°6'N	65	Europe	Belgium	3°51'E, 51°6'N
31	Asia	Korea	127°42'E, 37°30'N	66	Europe	Estonia	26°45'E, 58°46'1.2"N
32	Asia	China	112°31'1.2"E, 37°39'N	67	Europe	Finland	30°58'1.2"E, 62°46'58.8"N
33	Asia	China	115°25'8.4"E, 39°57'N	68	South America	Brazil	56°58'59"W, 3°4'1"S
34	Asia	China	87°51'25.2"E, 40°27'57.6"N	69	South America	Brazil	47°56'56"W, 1°17'53"S
35	Asia	China	117°15'E, 42°19'12"N	70	Africa	Côte d'Ivoire	5°13'1.2"W, 6°16'59"N

3.2 Fine root turnover in different types of forest ecosystems

The turnover of fine roots in different types of forest ecosystems is shown in **Table 2**. There were significant differences in fine root turnover among different forest types ($P < 0.05$). The turnover rate of fine roots in tropical forests is the highest, with an average of 1.312 a^{-1}; the turnover rate of fine roots in cold temperate forests is the lowest, which is 0.602 a^{-1}. Except for the higher temperate zone, the fine root turnover rate basically decreased with the increase of latitude.

Table 2. Fine root turnover rate in different types of forest ecosystem

Forest type	Data number	Means ± SE
Tropical rainforest	11	1.312 ± 0.182 a
Subtropical evergreen broad-leaved forest	9	0.802 ± 0.161 b
Warm temperate deciduous broad-leaved forest	13	0.724 ± 0.859 b
Temperate coniferous and broad-leaved mixed forest	30	0.766 ± 0.995 b
Cold temperate coniferous forest	7	0.602 ± 0.106 b

Note: Different lowercase letters within a soil layer indicate significant differences ($P < 0.05$), according to the Duncan post hoc test.

3.3 Relationship between fine root turnover and climate factors in forest ecosystem

The fine root turnover rate of forest ecosystem is significantly affected by temperature and precipitation (**Figure 2**) (P < 0.05). The annual average temperature in the study area is between 1.4–28.8 °C. Within this temperature range, there is a significant positive correlation between the fine root turnover rate of forest ecosystem and the annual average temperature (**Figure 2A**) (P< 0.05). The higher the temperature, the higher the forest fine root turnover rate. The annual average precipitation in the study area is 34–5,545 mm. Within this precipitation range, the fine root turnover rate of forest ecosystem is also significantly positively correlated with the annual average precipitation (**Figure 2B**) (P < 0.05). The greater the annual average precipitation, the higher the forest fine root turnover rate.

3.4 Relationship between fine root turnover and soil physical and chemical properties in forest ecosystem

The fine root turnover rate of forest ecosystem was significantly affected by soil organic carbon content and soil pH value (**Figure 3**) (P < 0.05). The study found that there was a significant positive correlation between soil organic carbon content and fine root turnover rate of forest ecosystem (**Figure 3A**) (P < 0.05), that is, the higher the soil organic carbon content, the faster the fine root turnover. However, there was a significant negative correlation between soil pH and fine root turnover rate of forest ecosystem (**Figure 3A**) (P < 0.05). There is no significant correlation between soil composition, soil bulk density and soil cation exchange capacity and fine root turnover rate of forest ecosystem (**Figures 3A–G**).

3.5 Correlation between factors

Latitude, annual average temperature, annual average precipitation, soil organic carbon and soil pH value are significantly correlated with fine root turnover of forest ecosystem (**Table 3**) (P < 0.05), but soil bulk density, soil cation exchange capacity, sandy soil content, loam content and clay content are not significantly correlated with fine root turnover of forest ecosystem (**Table 3**). In addition, there is a significant autocorrelation between latitude, annual average temperature, annual average precipitation and soil bulk density (**Table 3**) (P < 0.05); there is also a significant autocorrelation between soil bulk density, soil cation exchange capacity, sand content, loam content and clay content (**Table 3**) (P < 0.05).

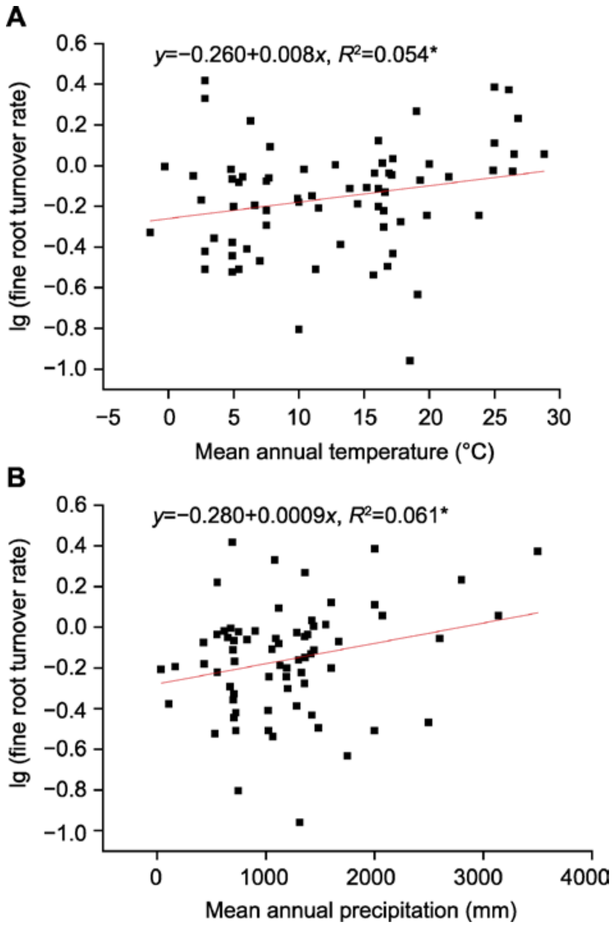

Figure 2. Relationships between fine root turnover rate in forest ecosystems and mean annual temperature **(A)** and mean annual precipitation **(B)**.
* indicates significant correlation at the 0.05 level.

3.6 Discussion and conclusion

3.6.1 Distribution of fine root turnover in forest ecosystems at different latitudes

The climate and forest types are different in different latitudes, which affect the distribution of aboveground vegetation and fine root turnover. It mainly affects the productivity and death rate of fine roots by affecting climate and forest types, and then affects the turnover of fine roots[33]. In this study, the fine root turnover rate of forest ecosystem decreases with the increase of latitude, which is

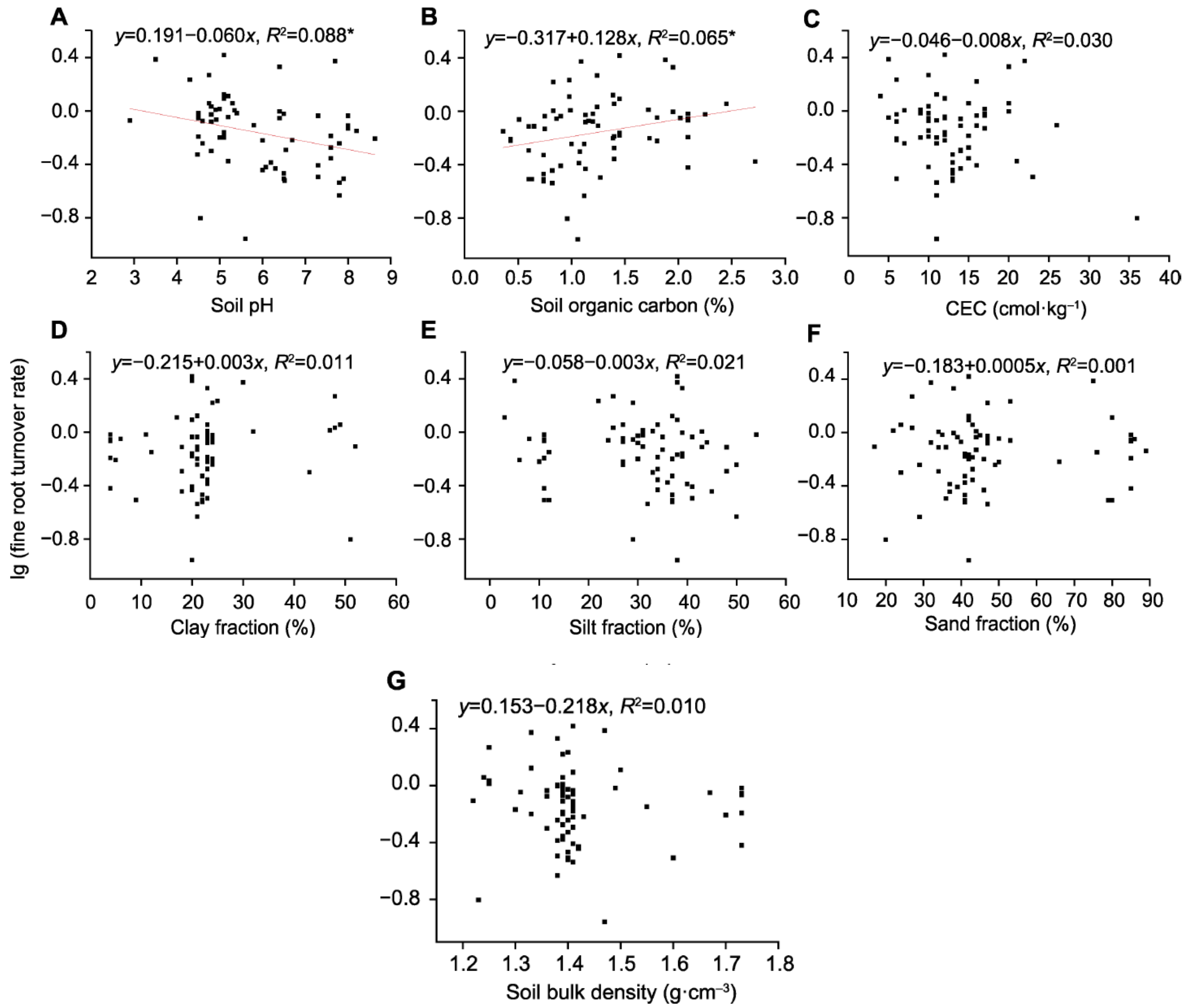

Figure 3. Relationships between forest fine root turnover rate and soil physical and chemical properties.
Note: CEC: Soil cation exchange capacity; * indicates significant correlation at the 0.05 level.

Table 3. Pearson correlations among latitude, mean annual temperature, mean annual precipitation, soil organic carbon content, soil pH, soil bulk density, CEC, sand fraction, silt fraction, clay fraction, and fine root turnover rate

	MAT	**MAP**	**Soil organic carbon**	**Soil pH**	**Soil bulk density**	**CEC**	**Sand fraction**	**Clay fraction**	**Silt fraction**	**Lg (fine root turnover rate)**
Latitude	-0.867**	-0.609**	-0.164	0.168	0.348**	0.157	0.124	0.097	0.105	-0.367**
MAT		0.576**	-0.029	-0.009	-0.332**	-0.03	-0.211	-0.011	0.361**	0.233*
MAP			-0.101	-0.094	-0.254*	-0.048	-0.167	0.052	0.221	0.240*
Soil organic carbon				-0.449**	0.14	0.11	0.126	-0.171	0.029	0.254*
Soil pH					0.026	0.235	-0.041	0.231	-0.165	-0.297*
Soil bulk density						-0.464**	0.900**	-0.599**	-0.852**	-0.098
CEC							-0.545**	0.376*	0.491**	-0.071
Sand fraction								-0.823**	-0.772**	0.038
Clay fraction									0.284*	-0.146
Silt fraction										0.104

MAT: Mean annual temperature; MAP: Mean annual precipitation; CEC: Soil cation exchange capacity. * and ** indicate significant correlation at the 0.05 and 0.01 level, respectively.

significantly negatively correlated with latitude. Among them, the fine root turnover of tropical rainforest is the fastest, about once every 9–10 months; the turnover of fine roots in coniferous and broad-leaved mixed forests in the cold temperate zone is the slowest, about once a year and a half. Comparing the turnover of forest fine roots in different climatic zones, it is found that there are obvious differences between tropical rainforest and other forest types. Liu *et al.*[25] reached a similar conclusion on the study of fine root turnover rate of *Pinus koraiensis* forest. In addition, Xiao *et al.*[24] found that the fine root turnover rate of subtropical forests is higher than that of warm temperate forests. Li and Ren[34] calculated the ratio of aboveground biomass to underground biomass of different forest types and found that the ratio of tropical rainforest to underground biomass was the smallest, indicating that the plant roots of tropical rainforest were more developed than other forest types, and the amount of litter and its decomposition rate of tropical forest were significantly higher than those of other forest types[35], which may also be the reason for the significantly high turnover rate of fine roots of tropical rainforest.

3.6.2 Influence of climate on fine root turnover

Climatic conditions affect soil temperature and moisture, plant species and habitat types, and then affect fine root turnover. Silver and Miya[36] studied the fine root data on a global scale and found that the annual average temperature was positively correlated with the fine root turnover rate. Yuan and Chen[37] found that in some forests in Eurasia and North America, MAT and MAP will affect the dynamic changes of fine root biomass, and fine root productivity and turnover will increase with the increase of mat and map. Mei *et al.*[16] found that the higher the soil temperature, the greater the fine root productivity, thus promoting the turnover and aging of fine roots and shortening the fine root life. Kosola *et al.*[38] studied the fine roots of citrus reticulata and found that on the same profile, with the increase of soil depth, the temperature decreased, the fine root life prolonged, and the turnover rate decreased.

This study shows that there is a significant positive correlation between forest fine root turnover and temperature, and the fine root turnover rate is also higher in areas with high annual average temperature, which is consistent with the research results of Silver and Miya[36] and Gill and Jackson[33]. There are two possible reasons for analysis: (1) the increase of ambient temperature within a certain range will enhance the enzyme activity in living cells of fine roots, accelerate metabolism, and the respiration of cells will be stronger in order to ensure a higher level of protein and membrane lipids renewal under the background of temperature rise[6]. The consumption of carbohydrates in fine roots will accelerate, making the change of root biomass faster, so the turnover rate will be higher; (2) with the increase of temperature, the mineralization rate of soil nutrients accelerates[33], the enzyme activity in soil microbial cells increases, and the decomposition of soil organic matter increases, resulting in the increase of water and inorganic salts in soil, which is conducive to the growth of fine roots. With the increase of temperature, the soil is difficult to freeze. At the same time, the warm soil is conducive to the activities of soil microorganisms and soil animals, thus accelerating the turnover rate of plant fine roots. In addition, the increase of temperature will increase the biomass of aboveground parts of plants, and then increase the number of litter. Henry *et al.*[39] showed that the quality of litter will also increase, which will increase the input of soil carbon and nitrogen, improve the soil texture, and promote the turnover of fine roots.

In terms of precipitation, the results of this study show that there is a significant positive correlation between the annual average precipitation and forest fine root turnover. The higher the annual average precipitation, the higher the forest fine root turnover rate, which is consistent with the research results of Yuan and Chen[37]. However, Gill and Jackson[33] found that precipitation had no significant effect on fine root turnover. Wang *et al.*[17]showed that the impact of annual average precipitation on fine root turnover is greater than that of annual average temperature, which may be because the change of annual average precipitation in China is much greater than that of annual average temperature. Wang[40] also proposed after analyzing fine root changes on a Chinese scale that future precipitation will have a greater impact on the growth and death of fine roots in China's forest ecosystem, and the impact on fine root turnover may be the first. Studies have shown that fine root biomass, productivity and turnover are largely affected by soil water availability, and precipitation is an important factor determining soil water availability[41,42]. Zhang *et al.*[43] found that the biomass of fine roots will increase with the increase of precipitation, and the availability of soil solute will also improve, thus speeding up the turnover of fine roots. In addition, the increase of precipitation will also promote the return of fine root nutrients, improve soil quality, and promote microbial growth. These changes will also further promote the turnover of fine roots.

3.6.3 Effect of soil physical and chemical properties on fine root turnover

Many properties of soil (such as soil moisture, temperature and nutrients) will affect the growth status and life span of fine roots, and then affect the turnover of fine roots[44]. Previously, many researchers have found that fine root turnover has an important contribution to soil organic carbon content. Lai[45] believes that the soil with richer fine roots accumulates more soil organic carbon due to the turnover of fine roots, and the soil microorganisms can use more raw materials for their own growth and development, which is conducive to root growth.

In this study, we found that soil organic carbon also has a significant impact on fine root turnover. The higher the content of soil organic carbon, the faster the fine root turnover. Wang *et al.*[46] found that some soil fungi can form mycorrhiza with fine roots, prolong the life of fine roots, and then reduce the turnover rate of fine roots. The high content of soil organic carbon and the high C/N in soil are more conducive to the growth of bacteria rather than fungi. Therefore, mycorrhizal formation is reduced, fine root death and regeneration are accelerated, and the turnover rate is increased. It can be seen that there is an interaction between fine root turnover and soil organic carbon. Accelerating fine root turnover can promote the accumulation of soil organic carbon, and the increase of soil organic carbon will act on fine roots. This means that the response of soil carbon pool to global change is not only the result of the direct action of some factors, but also the interaction of some factors may be the reason for the change of soil carbon pool.

Soil pH value is one of the main factors affecting its type, nature, microbial and plant growth, and is an important factor to measure soil quality. Diabate[47] found that reducing soil pH can improve the net productivity of fine roots and promote the turnover of fine roots in Songnen grassland. The soil pH value in this study ranges from 2.9 to 8.63, including acidic, neutral and alkaline soils. The results show that there is a negative correlation between soil pH and fine root turnover. Within the scope of the study, the lower the soil pH, the faster the fine root turnover, indicating that the acidic forest soil is more conducive to the fine root turnover. Sun *et al.*[6] studied the effect of soil pH on grass root turnover, and obtained similar results. In addition, Zhang and Zhang[48] showed that the soil with high pH value has reduced organic matter content, enhanced acid leaching process, reduced soil fertility, weakened root activity and slow fine root turnover. The experimental results of Wang *et al.*[49] showed that the enzyme activity of rhizosphere soil increased with the decrease of pH value, indicating that acidic soil is more suitable for the survival of soil microorganisms. At the same time, its activities are more frequent, and the decomposition of organic matter in the soil accelerates, promoting the turnover of fine roots.

This study also found that there were significant differences in fine root turnover rate among different forest types, and with the increase of latitude, the fine root turnover rate gradually decreased. At the same time, forest fine root turnover is affected by climate factors and soil properties. Annual average temperature, annual average precipitation and soil organic carbon content are significantly positively correlated with fine root turnover, while soil pH is significantly negatively correlated with fine root turnover. Climate factors and soil properties can affect fine root turnover of forests by affecting soil texture and soil microorganisms. This study discusses the influencing factors of fine root turnover on a global scale, and integrates the fine root turnover data of various data points around the world. It may be different from the research results of fine roots in individual regions, but to some extent, it reveals the law of fine root turnover on a global scale, which can provide data support for predicting the response of soil carbon pool to global climate change. However, the influence mechanism of soil microorganisms and soil inorganic ions on fine root turnover is not clear at present. Follow up studies should explore this aspect in depth in order to comprehensively analyze the influencing factors of soil carbon pool.

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Conflict of interest

The authors declared no conflict of interest.

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