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FACTORS AFFECTING SOIL RESPIRATION IN REFERENCE WITH TEMPERATURE'S ROLE IN THE GLOBAL SCALE①

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ABSTRACT: Soil respiration is CO_2 evolution process from soil to atmosphere, mainly produced by soil micro-organism and plant roots. It is affected not only by biological factors (vegetation, micro-organism, etc.) and environmental factors (temperature, moisture, pH, etc.), but also more and more strongly by man-made factors. Based on literature survey, main factors affecting soil respiration were reviewed. The relationships of soil respiration to latitude and to mean annual temperature were analyzed by using the data measured from forest vegetation in the world. As a result, soil respiration rate decreased exponentially with an increase of latitude, and increased with increasing temperature. Following the relationship between soil respiration and temperature, Q_{10} value (law of Van Hoff) was obtained as 1.57 in the global scale.

KEY WORDS: effect factors, Q_{10} value, latitude, soil respiration, temperature

I. INTRODUCTION

Soil respiration is CO_2 evolution process from soil to atmosphere. It is mainly produced by oxidizing organic matter by micro-organisms and the respiration of plant roots, and partially released from soil animal's respiration and oxidization (Raich *et al.*, 1992). As an important

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part of the carbon cycle in terrestrial ecosystems, soil respiration is usually used as an indication of soil organism's activity, soil fertility and soil aeration (Anderson *et al.*, 1975; Macfadyen, 1970; Reiners, 1968; Neilson *et al.*, 1990). Meanwhile, studies on soil respiration have been paid a great attention upon, as it is the only pathway of the soil carbon pool to atmosphere and the important source of atmospheric CO_2.

Early in the 19th century, people had paid attention to effect of soil CO_2 and soil O_2 on activities of soil organism (Saussure, 1804). In the second half of the 19th century and the beginning of this century, people had already started to measure soil respiration rate (Albert, 1912; Clements, 1921; Russel *et al.*, 1915). Since the 1960s, studies on soil respiration had been one of the hot topics in soil science and biology due to improvement of measurement methods and equipment and in order to meet a need of IBP (International Biological Program). Especially in recent years, the increasing atmospheric CO_2 concentration and the global climate change have become one of the focuses of the public and scientists; and therefore a special attention has been paid to the measurement of soil respiration as CO_2 released from soils is one of the most important greenhouse gases. As a huge carbon pool (1200×10^{15}– 1500×10^{15} g C) (Jenkinson *et al.*, 1991; Fang *et al.*, 1996), soil is one of the most important sources of atmospheric CO_2; about 68×10^{15} g C is released to air from soil annually (Raich *et al.*, 1992), while fuel burning about 5.2×10^{15}g/a C (Detwiler *et al.*, 1988). This means that even its small change will generate an big change of the CO_2 concentration in the air. Based on the literature review on data of soil respiration published around all the world, this paper will discuss main effect factors of soil respiration, and analyze change in soil respiration with the global climate change.

II. THE EFFECT FACTORS OF SOIL RESPIRATION

As a complicated biological process, soil respiration is affected by a variety of factors. Fig. 1 shows main effect factors.

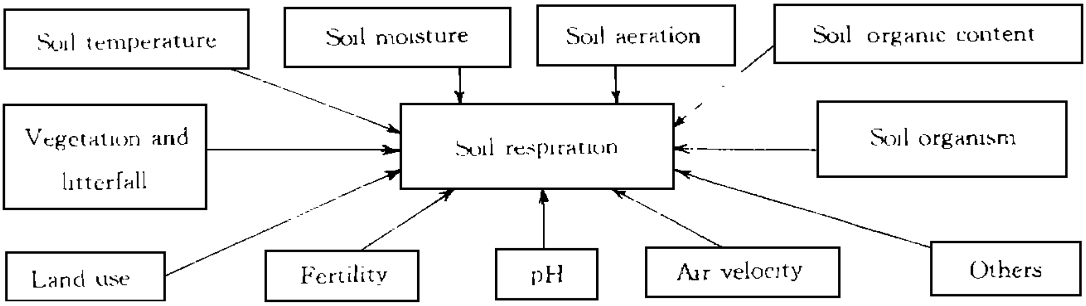

Fig. 1 Factors affecting soil respiration

1. Effect of Biological Processes

Although physical and chemical processes of soil, such as the oxidization of organic matter and the evolution of dissolved CO_2, etc., produce partially CO_2, much of CO_2 is produced by soil biological processes. In fact, soil respiration is approximately total CO_2 evolution amount by soil micro-organism, soil spineless creatures and plant roots. The respiration of soil spineless creatures is often neglected. The released CO_2 by the other two parts is actually quite difficult to precisely measure respective contribution for the reason that the plant roots and the root micro-organism in soil are usually difficult to be separated. The proportion of plant roots respiration varies greatly from instinctive to 1/3 of total CO_2, sometimes even more than 60% in different environments (Kucera *et al.*, 1971; Wiant, 1967; Edwards, 1975; Chapman, 1979).

As the activities of soil micro-organism depend on the input of organic matter from above-ground and root biomass of plants, and respiration of plant roots is an important component of total soil respiration, the effects of vegetation and litter-fall are of great significance. Moreover, the direct effect factors, such as soil organic content, pH value, temperature and moisture, vary remarkably with vegetation cover; the soil respiration varies consequently. As the main source of soil organic matter, litter-fall also affects significantly soil respiration (Fig. 2). Fig. 2 shows that soil respiration rate increases with an increase of litter-fall by using the data measured in different terrestrial ecosystems (Raich *et al.*, 1989). On the other hand, though respiration rate of soil animals plays an essential role in soil CO_2 emission as an important component of a soil ecosystem (Kretzchmar *et al.*, 1993; Bohlen *et al.*, 1995), few studies of the soil animals' effect on soil respiration have been carried out and therefore their mechanism keeps unclear.

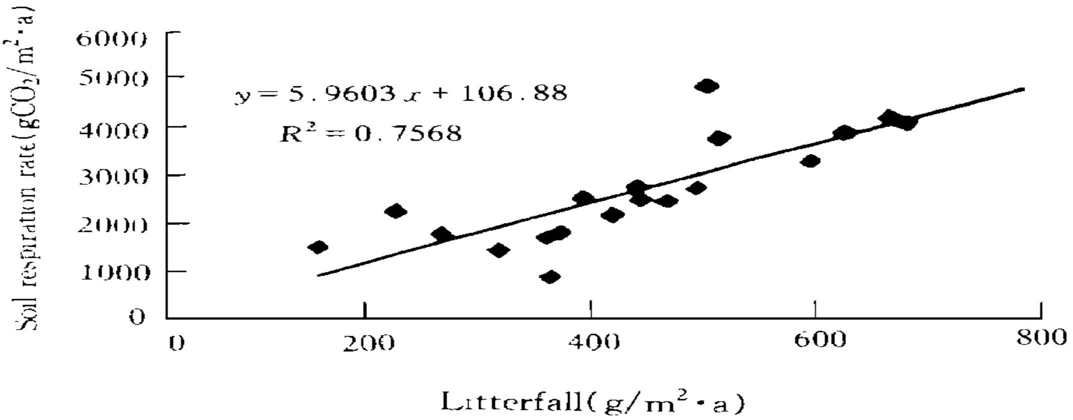

Fig. 2 Relationship between soil respiration and litter-fall (based Raich *et al.*, 1989)

2. Relationship Between Soil Respiration and Soil Temperature and Moisture

Early researchers have found that soil respiration are closely related with soil temperature and moisture. This is because that the biological activities in soil are strongly affected by the environmental factors. Many studies have proved that soil respiration shows a positive correlation with an increase of soil temperature at the condition of sufficient soil moisture content (Reiners, 1968; Anderson, 1973; Mathes *et al*., 1985; Nakane *et al*., 1984; Buyanovsky *et al*., 1986; Schkentner *et al*., 1985; Edwards *et al*., 1977) (Table 1), while in the

Table 1 Relationship between soil respiration and temperature

Site	Ecosystem type	Relationship	References
Sanborn Field, Columbia, Mo. USA	Winter wheat ecosystem	$\ln CO_2 = 7.0687 + 0.1329T - 0.002T^2$ $R^2 = 0.66$, where T is soil temperature at 10 cm depth	Buyanovsky, 1986
The University of Missouri Prairie Station, Callaway Country, Mo, USA	Tallgrass prairie	$\ln CO_2 = -1.66 + 2.20 \times \ln(T + 10)$ where T is soil temperature	Kucera, 1971
Western Maine, USA	Deciduous and conifer	$CO_2 = 0.1301 + 0.0064T$, $R^2 = 0.28$ where T is air temperature	Fernandez *et al*., 1993
Southern England	Heathland	$\ln CO_2 = 0.0841T - 2.0745$ $R^2 = 0.82$ where T is air temperature	Chapman, 1979
Alaska	Tundra	$CO_2 = 89.78 + 1.54T + 5T^2$ where T is mean daily soil temperature	Peterson *et al*., 1975
Mt. Takao in Fuchur cho, west Japan	Red pine forest	$\ln CO_2 = C + B_1T + B_2MI$ where C, B_1 and B_2 are coefficient and MI moisture index	Nakane *et al*., 1984
Cdar Creek Natural History Area, Anoka Co., Minn., USA	Temperate forest	$\log CO_2 = 1.9752 + 0.0425T$ where T is soil temperature	Reiners, 1968
Blean Woods National Nature Reserve, northeast Kent, UK	Temperate, deciduous woodland	Castanea site: $\log CO_2 = 1.9752 + 0.0425T$ where T is soil temperature	Anderson, 1973
Blean Woods National Nature Reserve, Kent, UK		Fagus site: $\log CO_2 = 1.9752 + 0.0425T$	Anderson, 1973
Aiken, SC, USA	Pine forest	$CO_2 = 0.715 + 0.210Ta + 0.285P_{3-1} + 0.083P_{7-4}$ where P_{3-1} is the precipitation of 3 days before experiment, P_{7-4} is the precipitation of 7-4 days before experiment, and Ta is ambient air temperature	Reinke *et al*., 1981
Eastern Tennessee	Mixed deciduous forest	$CO_2 = 0.0444T^2$ where T is temperature	Edwards, 1975

semi-arid and arid regions where moisture become a limiting factor, both moisture and temperature affect commonly regions on soil respiration (Wildung, 1975).

3. Effect of CO_2 Concentration

Some studies have demonstrated that respiration of roots and micro-organism is restrained by high soil CO_2 concentration (Macfadyen, 1973; Koizumi, 1991; Qi *et al.*, 1994). This means that the soil respiration may also be restrained when atmospheric CO_2 concentration rises.

4. Effect of Landuse Pattern

Land use patterns influence obviously rate of soil respiration. Different cropping patterns, such as the change in cultivation and in condition of irrigation and drainage, change not only vegetation but also physical characteristics of the soil (e.g., soil aeration and organic content, composition and activity of microorganism, and the biomass of roots). Consequently soil respiration will be quite different (Badia *et al.*, 1993; Chagas *et al.*, 1995). Human activities influence more and more strongly the global soil CO_2 flux. For instance, the temperate wetland has been changed to air CO_2 source originally from the CO_2 sink, especially due to change in irrigation and drainage condition (Armentano *et al.*, 1986). Lumbering of tropical forests has led an increase by CO_2 flux of $0.4\times10^{15}-1.6\times10^{15}$ g/a C (Detwiler *et al.*, 1988).

In addition, air velocity (Farrell, 1996), forest lumbering (Nakane, 1986; Fernandez, 1993), fertilization and irrigation (Silvola, 1985), soil chemical composition (Bunnell, 1977), pH (Baath *et al.*, 1994), etc. affect distinctly soil respiration rate.

III. EFFECT OF TEMPERATURE ON SOIL RESPIRATION IN THE GLOBAL SCALE

In order to eliminate the influence of moisture, data of soil respiration rate obtained from forest ecosystems in humid region were used to analyze the relationship between temperature and soil respiration rate in the global scale. Datasets reported by Schlesinger (1977) and Raich & Schlesinger (1992) were used to examine the relationship because the soil respiration rates throughout all the year were provided in their studies, and included boreal and temperate forests, and tropical and subtropical rain forests.

1. Variation of Soil Respiration According to the Variation of Latitude

As shown in Fig. 3, soil respiration rate decreases gradually with the increase of latitude, and is fit by the following equation (Eq. 1).

$$y = 1586^* \exp(-0.0237x) \qquad (R^2 = 0.47) \qquad (1)$$

In which y is soil respiration rate, and x latitude. Most of data in Fig. 3 are centered near the fitness curve, but a few points, especially data in low latitude region, are relatively far from the fitness curve. Estimation method of temperature, measurement method and instrument are main factors causing the errors between measured and estimated data. In lower latitudes, data of annual soil respiration are usually estimated from several-day-long or even several-hour-long measurements, and consequently the error is generated rather largely.

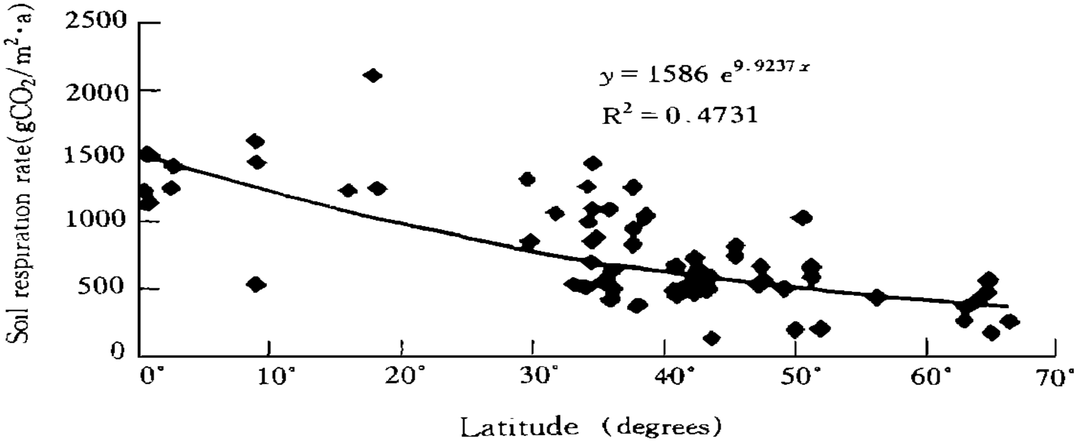

Fig. 3 Relationship between soil respiration rate and latitude

2. Relationship between Temperature and Soil Respiration

Due to lack of mean annual temperature at studied sites, the relationship between latitude and the mean annual temperature was first regressed, and then convert the data of the latitude into the mean annual temperature, and finally the Q_{10} value, which expresses the relationship between soil respiration and temperature at the global scale, was obtained.

2.1 Relationship between latitude and mean annual temperature

Although distribution of temperature is influenced by many factors, such as latitude, distribution of oceans and continents, altitude, and topography, as a general tendency temperature decreases gradually from the equator to the pole. The relationship between global mean annual temperature and mean latitude was fit by Eq. 2, using climatic data compiled by Tokyo Astronomical Observatory (1985). The data from the climatic stations with over 500 m above the sea level have not been used in fitting.

$$y = -0.0064x^2 - 0.0848x + 28.231 \qquad (R^2 = 0.90) \qquad (2)$$

where y presents temperature (℃), and x latitude (°N or °S).

2.2 Relationship between temperature and soil respiration rate

Fig. 4 displays the relationship between soil respiration rate and global mean annual temperature, which was converted based on Eq. 2 from the mean latitude in Fig. 3. It was regressed by Eq. 3, that is, the soil respiration rates of forest vegetation increase with an increase of mean annual temperature.

$$y = 349.66\exp(0.0449x) \qquad (R^2 = 0.47) \qquad (3)$$

In which y presents soil respiration rate, and x mean annual temperature.

From Eq. 3, the Q_{10} value was obtained as 1.57 in the global scale. This means that the soil respiration increases by 1.57 times in the global scale as temperature increases by each 10 ℃. Compared with other studies, the Q_{10} value in the global scale is relatively low. It means that the increase of the respiration rate is slower corresponding to the increase of temperature.

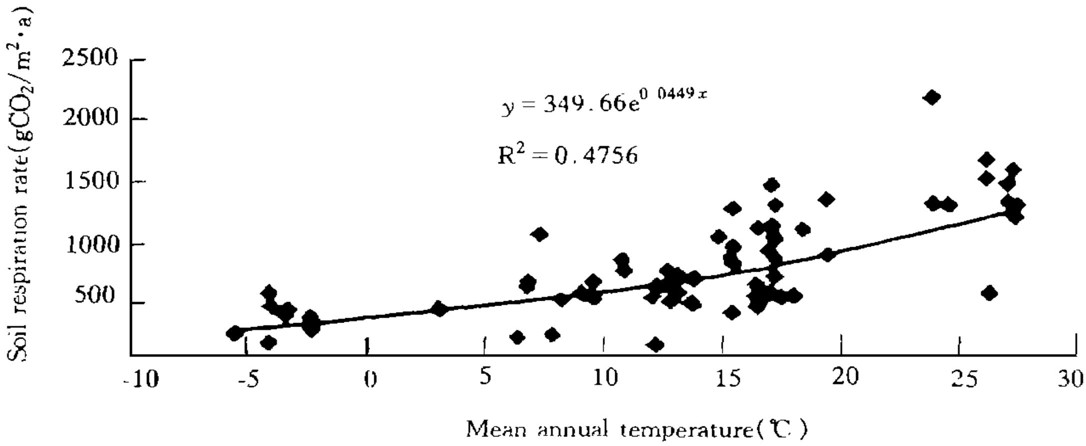

Fig. 4 Relationship between soil respiration rate and annual mean temperature

IV. DISCUSSION AND SUGGESTIONS

1. Interaction among Effect Factors of Soil Respiration

The effect factors of soil respiration discussed above are not independent, but affect commonly the soil respiration. For example, vegetation cover is not only closely coupled with the soil organic matter, but also affects the soil temperature, water content; wind changes not only diffusion coefficient of CO_2, but also soil water moisture due to changing evaporation of soil surface. That is to say, soil respiration is a complex biological process and is controlled by many abiotic and biotic factors.

2. Measurement Method of Soil Respiration

The measurement methods of soil respiration can be classified as direct measurement and indirect measurement (Singh *et al.*, 1977). The former includes static method and dynamic method, and is widely used in field studies (Witkamp *et al.*, 1969). Alkaline absorption measurement and infrared CO_2 absorption measurement are two main techniques for measuring CO_2 in field study. In past two decades the infra red CO_2 technique has greatly been improved and is gradually displacing the alkali absorption method. However, all these methods are not perfect, and need more improvement (Nakadai, 1993; Pajari, 1995). Worse comparability among the different data obtained from different methods is another large problem for studying soil CO_2 emission at a regional and global scales. For this reason, studying soil respiration by applying the standard methods is very important in the future.

3. Global Change in Relation with Soil Respiration

The temperature changes more slowly in lower latitudes than in higher latitudes (Fang *et al.*, 1998), but on the contrary, soil respiration varies more rapidly in lower latitudes than in higher latitudes (Fig. 3). This disagreement may be generated from the difference in production of the litter-fall and its decomposing rates. The production of litter-fall is closely coupled with latitude (Raich *et al.*, 1992; Raich *et al.*, 1989), and the decomposing rate of litterfall increases quickly in a high temperature condition. This leads to an exponential decrease of soil respiration rate with latitude as shown in Fig. 3, and to a storage of soil organic carbon in high latitude regions.

As indicated in Fig. 4, soil respiration rate is positively related with temperature. This means that the difference of soil respiration rate in different regions in the global scale is mainly caused by the variation of temperature. Therefore, it is expected that there would be an increase of the CO_2 emission from forest soils when the global temperature would rise up.

4. Suggestions On Future Work

The amount of global CO_2 evolution is estimated from data obtained by previous field studies, but the error produced from these studies is considered rather great due to the following reasons: 1) measurement method, particularly the alkaline absorption measurement, 2) unbalanced distribution of field sites (most study sites are located in the temperate region, while there are few measurements in the tropical zone and higher latitudes), 3) few measurements in the arid regions, and 4) effect of microclimate in estimating the global CO_2 flux (in most of cases, it has not been considered).

For the reasons discussed above, it is necessary in the future for us to make a great effort in improving the methods of measurement, increasing the field sites, and establishing the network for measuring CO_2 flux of soils around the world.

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