Daily variation of carbon flux in soils of *Populus euphratica* forests in the middle and lower reaches of the Tarim River*

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Abstract In order to lucubrate the daily variation of respiration in soils of *Populus euphratica* forests and analyze its relationship with environmental factors in the middle and lower reaches of the Tarim River, the LI-8100 instrument of soil CO_2 flux system was used to measure the parameters of soil carbon flux and air temperature 10 cm above ground surface along the profiles of Usyman, Archy River, Yengisu and Karday, and the relationships between the soil carbon flux and the soil moisture content were analyzed. The nonlinear regression analysis was carried out with the software SPSS13.0. We observed that: (1) soil respiration began to be restrained when the air temperature was up to 30℃ 10 cm above the ground surface; (2) the rates of soil respiration under the forests of *Populus euphratica* were significantly different at various moisture contents, the soil carbon flux was high along the Usyman profile, which has a high soil moisture content, and it was low along the profiles of Archy River, Yengisu and Karday, which has a low soil moisture content; (3) the exponential model can be used to explain the relationship between soil respiration and air temperature 10 cm above the ground surface. The average Q_{10} values along the profiles of Usyman, Archy River, Yengisu and Karday are 0.61, 0.16, 0.22 and 0.35 respectively, much lower than the average of the world; (4) there is a positive correlation between the soil carbon flux and the soil moisture content.

Keywords: ***Populus euphratica*, soil carbon flux, air temperature 10 cm above ground surface, soil moisture content, the Tarim River.**

Soil respiration is one of the most important processes in the carbon cycle of terrestrial ecosystems. The amount of CO_2 discharged by the soil respiration is only next to that fixed by the total photosynthesis of vegetation canopy[1]. Therefore, the accuracy in measurement of CO_2 amount discharged by soil respiration is a key to assess the biological process of ecosystem[2]. Carbon flux of soil has a close correlation with the environmental factors. The change of carbon flux of soil is mainly regulated by water content and temperature together[3], and of which, an exponential model is commonly used for showing the change of soil inspiration along with temperature[4—6]. But the concrete association between humidity and soil respiration has not yet been established[7—9]. Previous studies have focused on the seasonal changes of soil respiration and the relationship between soil respiration and the factors of water and temperature at the aneurolepidium Chinese prairie[10] and half-arid prairie[11] of temperate zones, savanna of the north Australian[12] and tall-grass prairie of the North America[13,14], a few on the *Populus euphratica* community in extremely arid regions[15,16].

Populus euphratica is the major constructive species to the desert forest at the banks of Tarim River, and as the biggest natural *Populus euphratica* pool of resources in the world, it occupies 54% and 89% of the total *Populus euphratica* forest area of the world and China respectively. Intensified water resource development in Tarim River basin, which changed the water condition of the terrestrial ecosystem of the lower reaches greatly, resulted in a situation of no water in the lower reaches of Tarim River, crossing a 320 km distance. And it inevitably influenced the respiration of plant root system and the composition of microorganism community. In this case, the soil respiration of *Populus euphratica* community will also change consumingly. In addition, the middle and lower reaches of Tarim River are in the warm temperate zone, the differences in mean annual temperature and in mean daily temperature are great. The accumulated temperature, which is not lower than 10℃ is mostly between 4100 and 4300℃

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and lasts for 180—200 days, and the evaporation capacity, exceeds the rainfall precipitation greatly. All of these make this region an ideal location to study the law of the influence of temperature and humidity on soil respiration in extremely arid environments and to investigate the responses of root system and soil microorganism to climatic changes. Moreover, the study on the change of soil carbon flux and its influencing factors in this region is of importance to determine the function of this region as a source/sink in the carbon cycle.

1 Methods

1.1 Natural conditions of the region

Surrounding Taklimakan Desert, the main stream of Tarim River spans 1321 km. The region of interest is located in the middle and lower reaches of the main stream of the Tarim River from Yingbazha to Taitema Lake (41°00′—39°47′N, 85°21′—88°22′E) (Fig. 1), which is in the warm temperate zone, belonging to the arid desert climate with wind-drifting sand, floating dust, long sunshine duration and big temperature difference with the annual mean diurnal range of 14—16℃ and the annual maximum diurnal range above 25℃. The annual mean temperature variability is 0.5℃ from the middle reaches to the lower reaches of the river, and the yearly precipitation reduces from 41 mm at the middle reaches to 25 mm at the lower reaches, the yearly evaporation capacity increases from 2778 mm at the middle reaches to 2906 mm at the lower reaches, and the aridity index increases gradually from the middle reaches to the lower reaches. The physical makeup at the ground surface consists of fine sandy loam and the major constructive species are *Populus euphratica* and *Tamarix spp*.

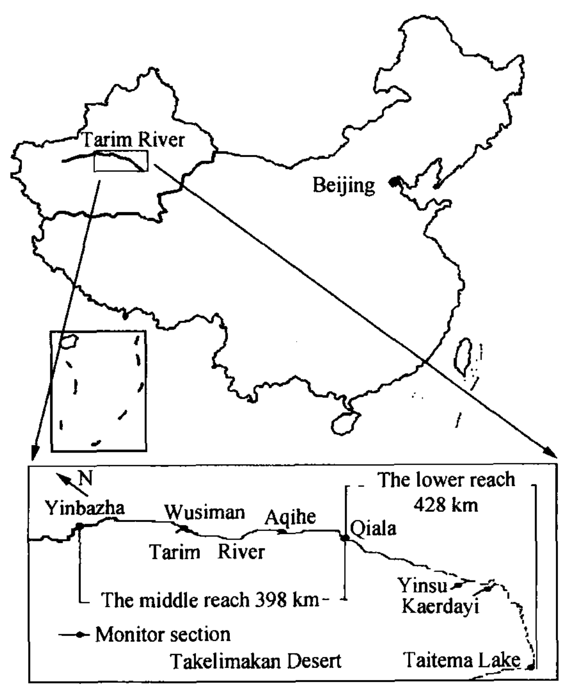

Fig. 1. Schematic of monitoring locations and sections at the middle and lower reaches of Tarim River.

1.2 Experimental methods

The experiments were conducted during a period of September 1—20, 2005. Four observation sections were set at Usman and Archy River along the middle reaches and at Yingsu and Kerdayi along the lower reaches. At each section, a sampling area was defined near the monitoring well of groundwater, where five PVC collars were inserted 8 cm deep into the ground in a plum blossom pattern so that five duplications of the measurements of soil carbon flux using the LI-8100 automated soil CO_2 flux system could be obtained. The soil samples were taken for the measurements of diurnal variation with regard to the soil respiration of the major constructive species, *Populus euphratica* community. Soil respiration was monitored from 8 am to 8 pm with an interval of 2 hours. Simultaneously, the air temperature within the *Populus euphratica* community was measured with a psychrometer and the 10 cm-above-ground air temperature was real-time monitored with WMY-01C digital temperature measuring meter. Due to the fact that underground water and soil moisture did not change much within one day in the arid area, both of them were observed within a single day, and soil samples at the depth of 5—15 cm were collected to measure the soil moisture content with the drying method. All statistical data were analyzed with SPSS13.0 software, and the difference in diurnal variation of soil respiration of *Populus euphratica* community at various sections was analyzed for multiple comparisons with AVOVA program. Non-linear regression program was used to analyze the relationship between soil carbon flux and air temperature at 10 cm above ground. The exponential model[17] used is: $Rs = ae^{bT}$, where Rs refers to soil respiration; T is temperature; a is soil respiration at 0℃ which is also called the basic respiration by some researchers; b is temperature response coefficient which reflects how sensitive the response of soil respiration to temperature is. In fact, the first power exponent model Q_{10}[17] is commonly used.

The Q_{10} value could be determined by $Q_{10} = e^{10b}$, in which, b is as the same as above. The nonlinear program was used to analyze the relationship between the average soil respiration of various communities and temperature, also the relationship between Q_{10} and temperature.

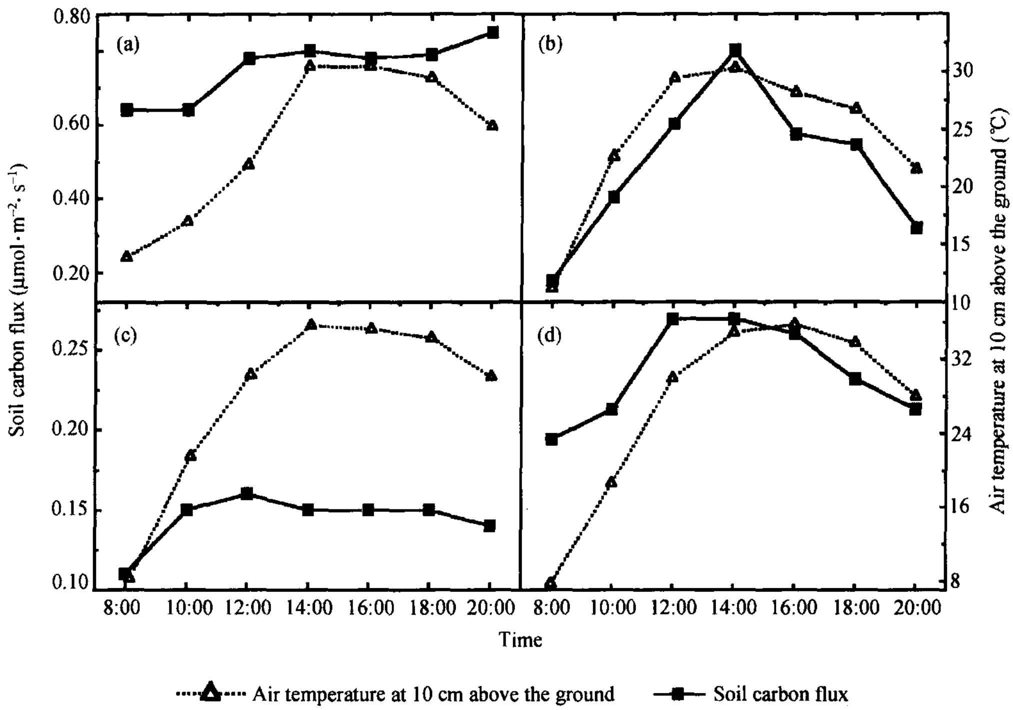

Fig. 2. Soil carbon flux and air temperature at 10 cm above the ground surface at each section. (a) Usyman; (b) Archy River; (c) Yengsu; (d) Karday.

2 Result and analysis

2.1 Diurnal variation of soil respiration and air temperature near the ground surface

The average values of five-duplication of soil carbon flux and the average values of air temperature at 10 cm above the ground surface at each monitoring section were used for the presentation of the results illustrated in Fig. 2.

It can be seen from this figure that the diurnal variation is fairly consistent and the values of soil carbon flux are relatively small within a range of 0.02—0.9 μmol·m^{-2}·s^{-1}, although the ranges of air temperature change near the ground surface at the sections are not completely same. However, there are still some differences in the scope of the change and diurnal variation dynamics because of the different zones, i.e. the maximum carbon flux at the middle reaches appeared at 14:00 with reversal trend after that time, but the carbon flux at the lower reaches arrived at the maximum value at 12:00 and then the soil respiration was restrained and declined; the air temperature near the ground surface exceeded 30℃ at 14:00 at the middle reaches and at 12:00 at the lower reaches respectively, which shows that the soil respiration was restrained when the air temperature reached 30℃. Usman and Archy River both are located at the middle reaches of Tarim River and Yingsu and Kerdayi the lower reaches of Tarim River. The change of carbon flux of soil respiration at the middle reaches was 0.16—1.29 μmol·m^{-2}·s^{-1}, and at the lower reaches was 0.09—0.39 μmol·m^{-2}·s^{-1}. The average carbon flux was 0.49 μmol·m^{-2}·s^{-1} at the middle reaches and 0.19 μmol·m^{-2}·s^{-1} at the lower reaches. In the case that both carbon fluxes are not very big, the value at the middle river reaches would be bigger than that at the lower reaches, and for the vegetation coverage at the middle reaches is greater than that at the lower reaches. The result of linear regression analysis indicated that the exponential model fitted the relationship well between soil respiration and air temperature near the ground surface at every cross section (R^2 = 0.6796—0.9418, significance < 0.0002—0.0228), and of which, the correlation at Archy River section is best (R^2 = 0.9418, significance $=0.0002$) (Fig. 3). Q_{10} is a temperature-sensitive index of the soil respiration[16]. The values of Q_{10} at the four sections are 0.61 at Usman, 0.16 at Archy River, 0.22 at Yingsu, and 0.35 at Kerdayi, that means that, with every 10℃ rise of the air temperature at 10 cm above the ground surface, the rate of soil respiration at the four sections would increase respectively by 0.61, 0.16, 0.22 and 0.35 times, all are far lower than the worldwide average level (2.4), also lower than of the forestry community at the adjacent latitude (43°N, 121°E) and that of temperate grassland (43°N, 115°E). This shows that the sensitivity of soil respiration to temperature in the investigated region is far lower than those in other areas.

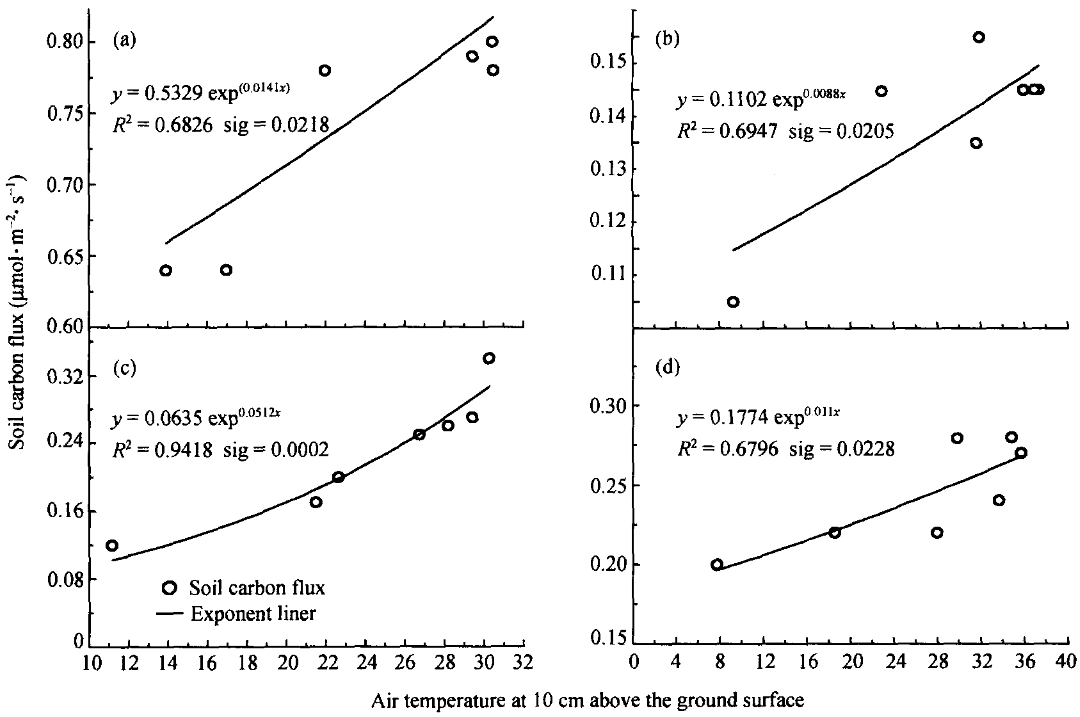

Fig. 3. Relationship between soil carbon flux and air temperature above the ground surface at each section. (a) Usyman, (b) Yengisu, (c) Archy River, (d) Karday.

2.2 Relationship between soil respiration and soil moisture content

The variance analysis indicated that the population difference in the daily change of soil respiration of *Populus euphratica* community at each section was extremely remarkable during the whole monitoring period (significance $=0.000$). The soil carbon flux at Usman was the biggest one (1.56 $\mu mol \cdot m^{-2} \cdot s^{-1}$), which was 4.2 times and 0.6 times of that at the lower reaches (Yingsu and Kerdayi) respectively. The multiple comparison result demonstrated that the significances of difference at various sections are not consistent. Generally speaking, the carbon flux at Usman section with larger soil moisture content was higher than the values at Archy River, Yingsu and Kerdayi sections where the soil moisture content was relatively low.

Water is the most significant environmental factor affecting the ecosystem in arid areas[18], therefore, even the slight improvement of soil water can remarkably change the plant root system and the microorganism's activity. Thus soil moisture becomes a determinant to the diurnal variation of carbon flux. By comparison of 10 samples collected at each section a similar tendency of both the soil carbon flux and the soil moisture content was found. The peak and the valley-bottom values of soil carbon flux were nearly in the same phase with the change of soil moisture content (Fig. 4(a)), which suggests a close relation between soil moisture content and carbon flux. In addition, nonlinear regression analysis showed the exponential model fits the relationship between the soil respiration of each community and the water moisture content at 5—15 cm depth ($R^2 = 0.5377$, significance $=0.016$) (Fig. 4(b)).

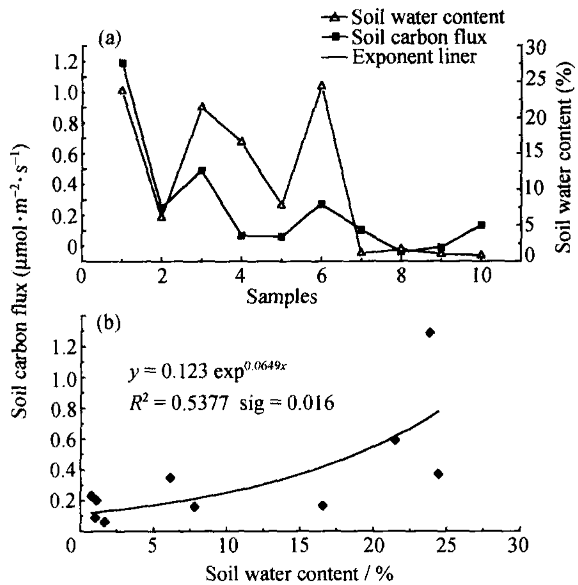

Fig. 4. Change of soil carbon flux and soil water content (a) and the relationship of them at the 5—15 cm depth (b).

3 Discussion

In the study of the relationship between the seasonal change of soil respiration and environmental factors, the researchers are accustomed to use the exponential model Q_{10} value to explain the change of soil respiration along with the air temperature and ground temperature[4—6]. This method has been widely used in the studies at temperate-zone half-arid aneurolepidium chinense prairie[10,19,20], savanna[12] and half-arid prairie area in south US[21]. And in this study, the exponential model also fits the response of soil respiration to the change of temperature at every section of *Populus euphratica* community.

We found that all the values of soil carbon flux at every section in the studied area were small, probably because some oxygen metabolism-related enzymes in the plant root system and in the edaphon were inactivated when the temperature exceeded a certain limit[22]. The soil carbon flux reduced gradually at four sections when the 10 cm-above-ground air temperature exceeded 30℃, which is the so-called thermal adaptation phenomenon[23], namely low Q_{10} value at high temperature and high Q_{10} value at low temperature[24].

The worldwide average Q_{10} value is 2.4, but all the Q_{10} values at the four sections in our study were smaller than the worldwide average value, indicating that the soil respiration is insensitive to the change of temperature in the region we studied during the experimental period. Wildung et al.[11] studied the soil respiration of the half-arid prairie area at Washington of east US, and found out that the influence of temperature on soil respiration reduced to be the secondary factor when the temperature exceeded 15℃. Chen et al.[19] also found that the exponential model we used fits better at low temperature than at high temperature when he studied the response of soil respiration of 11 plant communities in the temperate-zone prairie to the air temperature in summer and autumn. The temperature at the middle and lower reaches of Tarim River generally exceeds 15℃, so it is reasonable that the Q_{10} value is small under such a high temperature condition.

Water is one decisive factor for the plant to survive under the extremely arid condition. When the temperature is high, the limit of water content condition will reduce the capacity of soil respiration that should rise along the rise of temperature[24,25]. The soil carbon flux and the soil moisture content were related closely with each other in this area, which matches those results about the seasonal arid prairie at north Queensland in Australia[26], tall-grass prairie in North America[13,14], and aneurolepidium chinense prairie in the Xinlin River basin[20]. Parker et al. studied the soil respiration of one arid grazing meadow and found that the activation energy of soil respiration changed from 84.9 $kJ \cdot mol^{-1}$ to 39.5 $kJ \cdot mol^{-1}$ when the dry soil became humid, which indicated that the sensitivity of soil respiration to temperature increased along with the increase of soil water[27]. In our study, the Q_{10} value also increased from 0.35 to 0.61 when the soil moisture content increased from 0.88% to 22.63%, which indicated that the sensitivity of soil respiration to the temperature tended to increase with the rise of soil moisture content. Thus the soil inspiration in the arid area also is influenced by the conditions of the soil moisture content. But the relationship between the soil respiration and the soil moisture content at different research sites has not been confirmed. Chen et al. used the linear model to fit the relationship between soil respiration and soil moisture content at typical degraded prairie community of Xinlin River basin. We used the exponential model to address the relationship between the soil carbon flux and the soil moisture content because the annual mean evaporation capacity is 48 times of the annual mean rainfall in the arid area, and the water in soil mainly comes from surface runoff and ground water absorbed by vegetation root system. Under the conditions of high temperature and aridity, the effect of temperature on the soil respiration is not as strong as moisture content does.

In the past over 100 years, the measuring method and technology regarding soil inspiration have been improved constantly from the *in situ* mensuration to the static and dynamic mensurations[28,29]. Among them, the alkali absorption method is widely used at present, which can monitor soil respiration at several sites in a field simultaneously to obtain the data of the soil respiration on a larger temporal and spatial scale. However, it prevents the gas inside the observation body from exchanging with the air outside, disturbing the natural state. In our study, we used infrared method with the LI-8100 automated soil CO_2 flux system to monitor the soil respiration. This instrument has an exhaust pipeline to reduce pressure, which keeps the pressure balance between the air chamber and the atmosphere and reduces the error caused by "the air chamber effect". This method is simple, fast and precise, but the equipment required is expensive, which limits the big-scaled measurement of soil respiration.

In this study, we only explored the effect of diurnal variation of soil respiration and air temperature at 10 cm above the ground surface on the soil moisture content at four experimental sites for a period of 20 days. In fact, total soil respiration involves several biological and non-biological processes. Therefore, the factors like soil organisms, plant root systems, vegetation coverage and soil nutrient etc. could influence directly or indirectly the soil respiration rate, to different extents, when the conditions of water or heat change. Under certain conditions, those factors even conceal or revise the influence of water and heat on soil respiration. On the other hand, the influences of those factors on soil respiration will be appeared only after a long time, so a long-term and continuous monitoring of their influences on the soil respiration of *Populus euphratica* communities at the desert banks of the Tarim River, is needed to reveal the true profile of soil respiration in this region on a greater temporal scale.

4 Conclusions

(1) For the *Populus euphratica* communities at the middle and lower reaches of Tarim River, the diurnal variation curve of CO_2 emissions in the soil had a single peak. The maximum values of carbon flux presented at 14:00 at the middle reaches with a reversal trend, but at the lower reaches, the value of soil respiration was restrained and began to drop after the peak at 12:00. The study revealed a close relationship between soil carbon flux and air temperature near the ground surface, which is also affected by the vegetation coverage.

(2) In Tarim River basin, the air temperature near the ground surface is an important factor to decide the soil carbon flux of *Populus euphratica* communities, and the exponential model fits well the relationship between the soil respiration of communities and the air temperature at 10 cm above the ground surface at each sections.

(3) The Q_{10} values of four sections at the middle reaches and lower reaches of Tarim River were calculated as: 0.61 for Usman, 0.16 for Archy River, 0.22 for Yingsu and 0.35 for Kerday. All of them are far lower than that of the worldwide average and that of the forest and the prairie community at adjacent latitude, which indicates that the sensitivity of soil respiration to temperature in this area is far lower than that in other areas.

(4) The changes of soil carbon flux and soil moisture content showed a similar tendency at the middle and lower reaches of Tarim River, which indicates that the soil moisture content has an important effect on soil respiration, and the exponential relationship fits them well.

(5) In the *Populus euphratica* communities at the middle and lower reaches of Tarim River, the sensitivity of soil respiration to temperature tends to increase with the enlargement of soil moisture content, which indicates that the sensitivity of soil respiration to temperature is still affected by the condition of soil moisture content under the arid condition.

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