Vol 4 No 2 2005

# Diurnal Variations of Greenhouse Gas Fluxes from Mixed Broad-leaved and Coniferous Forest Soil in Dinghushan*

ZHOU Cunyu[1] ZHANG Deqiang[1] WANG Yuesi[2]
ZHOU Guoyi[1] LIU Shizhong[1] TANG Xuli[1]

1. South China Botanical Garden, Chinese Academy of Sciences, Guangzhou 510650, P.R.China
2. Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, P.R.China

**Abstract:** The subtropical mixed broad-leaved and coniferous forest, a typical successional monsoon forest, is one of the major forests in the subtropics of China. Therefore, it is very important to estimate the fluxes of the greenhouse gases from the forest soil in order to evaluate the impact of subtropical forests on the greenhouse gas emissions or absorptions. This study investigated the diurnal variations of fluxes of three greenhouse gases ($CO_2$, $CH_4$, and $N_2O$) from a mixed broad-leaved and coniferous forest soil. A static chamber-gas chromatograph technique was used to measure the fluxes of three greenhouse gases. By using the improved gas chromatography sampling system, the fluxes were analyzed with a single injection. In order to find out the effects of litter and seedling on the emissions or absorptions of these greenhouse gases, three treatments were set in the field:(1)bare soil surface (litter was removed previously); (3) litter + soil; (3) seedling + litter + soil. The experimental results demonstrated that the forest soil was a source of $CO_2$, $N_2O$ and a weak sink of $CH_4$.The daily fluxes of $CO_2$, $CH_4$, and $N_2O$ from the soil surface were in the range of 488.99~700.57, 0.049~0.108 and –0.025~ –0.053 mg/(m$^2$·h ), respectively. $CO_2$ from the litter decomposition accounted for about 1/3 of the total $CO_2$ emission from the soil surface, while the litter and seedling had no significant effect on the fluxes of $CH_4$ and $N_2O$. The fluxes of $CO_2$ and $N_2O$ measured at 9:00 –11:00 a.m. were significantly different from their daily averages. Therefore, caution must be taken if the $CO_2$ and $N_2O$ fluxes measured within 9:00–11:00 a.m. are used for extrapolation.

**Key words:** greenhouse gas, emission, absorption, flux, diurnal variation, broad-leaved and coniferous forest, Dinghushan

The atmospheric concentrations of $CO_2$, $CH_4$ and $N_2O$, which are the most important greenhouse gases in the atmosphere, have been increasing with unprecedented rates since the time of the industrial revolution, mostly owing to human activities. Currently, annual increases of the $CO_2$, $CH_4$, and $N_2O$ concentrations in the atmosphere are 1.5 mL/m$^3$, 4.0 μL/ m$^3$, and 0.8 μL/ m$^3$, respectively (IPCC, 2001, 1995). The increase of greenhouse gases in the atmosphere may lead to global climate change, which could affect natural and social systems in turn, therefore more and more attention has been paid to the sources and sinks of the greenhouse gases worldwide in recent years. In China, the corresponding work started relatively late and most of which focused on agriculture and grassland ecosystems (Dong Yunshe, et al, 2000; Du Rui, et al, 1998; Wang Mingxin, et al, 1998; Wang Yuesi, et al, 2000 ), while the research on the source and sink of greenhouse in forest ecosystem is not enough (Dong Yunshe, et al, 2003; Liu Yunfeng, et al,

*Supported by the Knowledge Innovation Funds from the Chinese Academy of Sciences (KZCX1-SW-01, KSCX2-SW-120).
Biography: ZHOU Cunyu, Ph.D. Mainly engaged in ecosystem ecology.

2001; Sun Xiangyang, 2000) and no result about the measurement of $CO_2$, $CH_4$, and $N_2O$ fluxes from forest soil at the same time has been reported yet.

This study is a part of a much larger study on estimating greenhouse gas emissions from a typical subtropical forest ecosystem in southern China. The objective of this study was to investigate the diurnal variations of emissions of three greenhouse gases ($CO_2$, $CH_4$, and $N_2O$) from the soil in a mixed broad-leaved and coniferous forest in Dinghushan. The mixed broad-leaved and coniferous forest usually occurs where evergreen monsoon rainforest was destroyed, and occupies a significant area in subtropical region China. So far very few studies have been carried out on quantifying emissions of greenhouse gases from this type of forest ecosystem, accurate determination of those emissions is therefore very important.

# 1 EXPERIMENTS AND MEASUREMENTS

## 1.1 Site Description

The flux measurement was carried out in a mixed broad-leaved and coniferous forest in Dinghushan Biosphere Reserve (112°30'39"~112°33'41" E, 23°09'21"~ 23°11'30" N), which is the first natural reserve in China. The reserve has an area of 1 145 ha with subtropical monsoon climate, annual average precipitation 1 956 mm, 76% of which concentrating on April to September; annual average air temperature 20.9 °C and annual average relative humidity 80%. The forest originated from artificial or natural *Pinus massoniana* forest after invasion by broad- leaved trees, is a representative forest type at the mid-successional stage and it is stepping in monsoon evergreen broad-leaved forest. Its above ground vertical structure can be divided into four layers: two arbor layers, a shrub layer and a grass layer. The above ground biomass of this community is 26 kg/m$^2$ approximately. Among its floristic compositions, evergreen plant species are absolutely dominant and most of elements are of tropics and subtropics.

## 1.2 Methods

Simultaneous measurement of $CO_2$, $CH_4$, and $N_2O$ were carried out with a frequency of once every two hours from 9:00 a.m. to 8:00 a.m. of next day (26 to 27, July, 2003). In order to find out the effects of litter and seedling on the emissions or absorptions of these greenhouse gases, three treatments were applied in the experimental plot: (1) bare soil surface (litter was removed previously); (2) litter + soil; (3) seedling + litter + soil. Meanwhile, environmental factors such as air temperature, soil temperature at surface and in the depth of 5 cm were also measured with digital thermometer.

## 1.3 Flux Measurement and Technique

The fluxes of the three greenhouse gases were measured by using static chamber-gas chromatograph technique. Each sampling chamber was made of 2 mm thick stainless steel and consisted of two parts: chamber pedestal and top chamber. The top chamber was 50 cm high, the base area of which was 50 cm×50 cm. Chamber pedestals were inserted to the soil in advance and adhesive tapes were stuck into the grooves on pedestals to prevent the gases from exchange between the chamber and atmosphere. In each top chamber, two small fans were used to improve chamber air circulation. Gas samples were collected by using 100 mL nylon syringe for 10 min intervals within 30 min. Then the concentrations of the gas samples were analyzed by using HP 4890 D Gas Chromatogram (GC) equipped with Flame Ionization Detector (FID) and Electron Capture Detector (ECD) within 12 h. By using the improved gas chromatography sampling system, the fluxes of the three greenhouse gases were analyzed with a single injection. $CO_2$ was separated with 2 m column with inner diameter 2 mm, 60~80 mesh Porapak Q Column, and an oven temperature 55 °C, and high-pure nitrogen carrier gas, with a flow speed of 30 mL/min; $CH_4$ was separated with 2 m column with inner diameter 2 mm, 60~80 mesh 13 XMS Column, and also high-pure nitrogen carrier gas, with a flow speed of 30 mL/min. For $N_2O$, the GC had a back flush system with stainless steel precolumn (3.2 mm O.D. and 1.84 m in length) and analytical column (3.2 mm O.D. and 3.68 m in length) packed Porapak Q with 80~100 mesh for both, and the oven temperature was held at 55 °C. The ECD temperature was maintained at 330 °C.

### 1.4 Flux Calculation

The gas flux was computed from the concentration change over the measurement period. The positive value denotes the gas emits into the atmosphere from the soil and the negative value represents the gas flows from the air to the soil or the soil absorb the gas from the atmosphere. It can be expressed as follows:

$$F = \frac{\Delta m}{\Delta t} \bullet D\frac{V}{A} = hD\frac{\Delta m}{\Delta t}$$

where:

$F$ refers to gas flux, mg/(m$^2$·h);

$\frac{\Delta m}{\Delta t}$ denotes linear slope of concentration changing with time over measurement period;

$D$ is the gas density in the chamber ($D = n/v = P/RT$, mol/m$^3$, $P$ the air pressure, $T$ the temperature inside of the chamber and $R$ the air constant);

$h$ represents the height of the chamber.

## 2 RESULTS AND DISCUSSIONS

### 2.1 Diurnal Variation Patterns of Fluxes

The diurnal variation patterns of emissions or absorptions of the three kinds of greenhouse gases from forest floor (with litter), air temperature and soil temperature in the depth of 5 cm are shown in Figure 1.

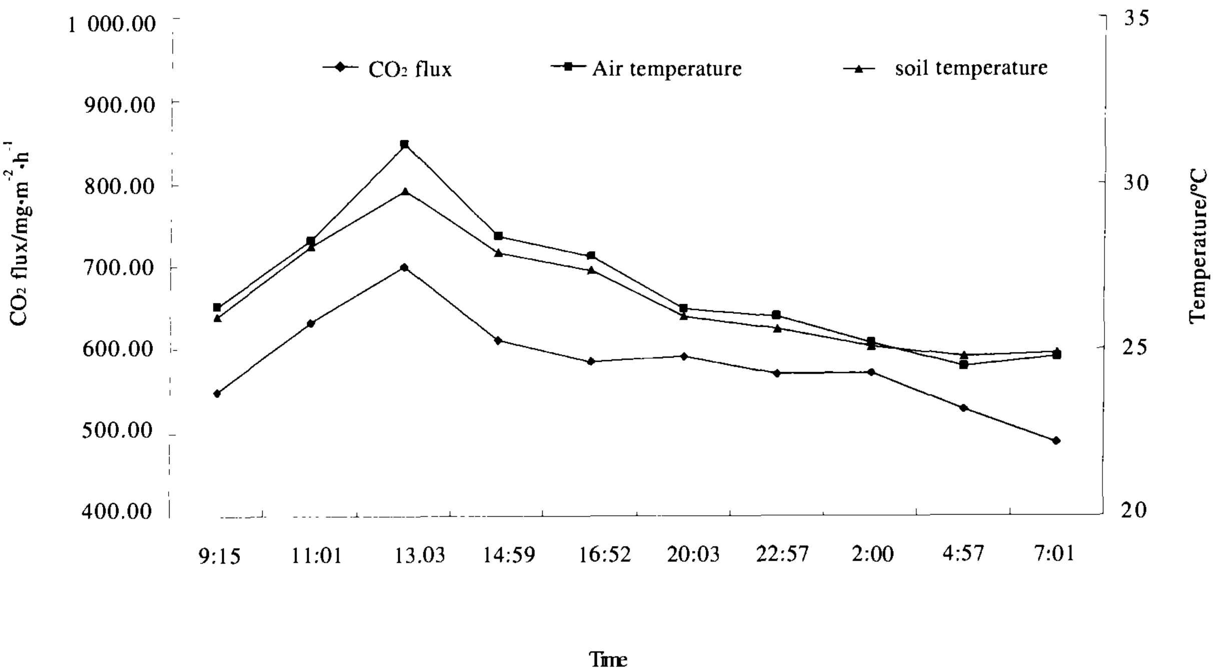


**Figure 1. Diurnal variations of $CO_2$ flux, air temperature and soil temperature**

The flux values of $CO_2$ and $N_2O$ are positive, while those of $CH_4$ are negative in the whole day, indicating that the forest soil in this study is a source of $CO_2$ and $N_2O$, but a sink of $CH_4$.

Figure 1 shows that the range of diurnal variation of $CO_2$ fluxes is 488.99~700.57 mg/(m$^2$·h). Compared with the results of diurnal variation of $CO_2$ fluxes in other ecosystems that have been reported (Dong Yunshe, et al, 2003; Dong Yunshe, et al, 2000; Du Rui, et al, 1998 ), the $CO_2$ flux from this forest soil changed more gently in measurement day, which may be attributed to the smaller daily variation of air temperature and soil temperature in this study area. $CO_2$ emission from forest floor mainly comes from heterotrophic respiration of soil microbes and soil animals, autotrophic respiration of plant root. The respiration intensity of these organisms (or one part of organism) increases with the temperature in a certain extent, so the daily variation of $CO_2$ flux increases with the temperature. Regressive analysis showed that $CO_2$ flux was significantly correlated with both air temperature and soil temperature ($R_{at}$=0.61, $P$<0.05; $R_{st}$=0.62, $P$<0.05; $R_{at}$ refers to correlation coefficient between $CO_2$ flux and air temperature; $R_{st}$ refers to correlation coefficient between $CO_2$ flux and soil temperature in the depth of 5 cm below the ground).

Figure 2 shows that the variation of $CH_4$ flux with higher consumption at nighttime and lower consumption during daytime, the results are similar to those obtained from the grassland of Inner Mongolia ( Dong Yunshe, et al, 2000) and forest soil of Gongga mountain (Dong Yunshe, et al, 2003). However, the influencing factors are still unclear, and more studies are needed.. The diurnal variation of $CH_4$ flux in this forest was also small, compared with that in Inner Mongolia grassland and forest soil of Gongga mountain, respectively, which might be also the result of smaller daily variation of temperature in this area.

For diurnal variation of $N_2O$ flux, there are great fluctuations but no apparent regularity. The maximum of $N_2O$ flux occurred at nighttime while the minimum occurred in daytime, which was contrary to the results of other related studies in China (Dong Yunshe, et al, 2003, 2000; Du Rui, et al, 1998; ). The reason might be that it is easy to produce anaerobic micro-zones in rain season when the soil moisture is higher. At this time, $N_2O$ emission from soil mainly comes from denitrification, in the process of which the ratio of

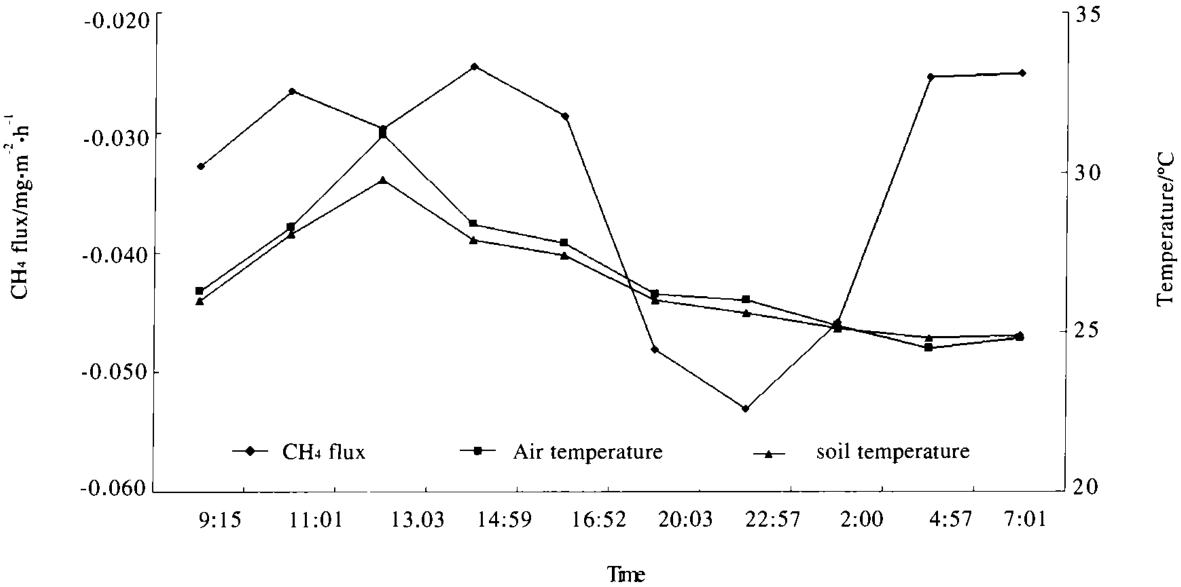


**Figure 2. Diurnal variations of $CH_4$ flux, air temperature and soil temperature**

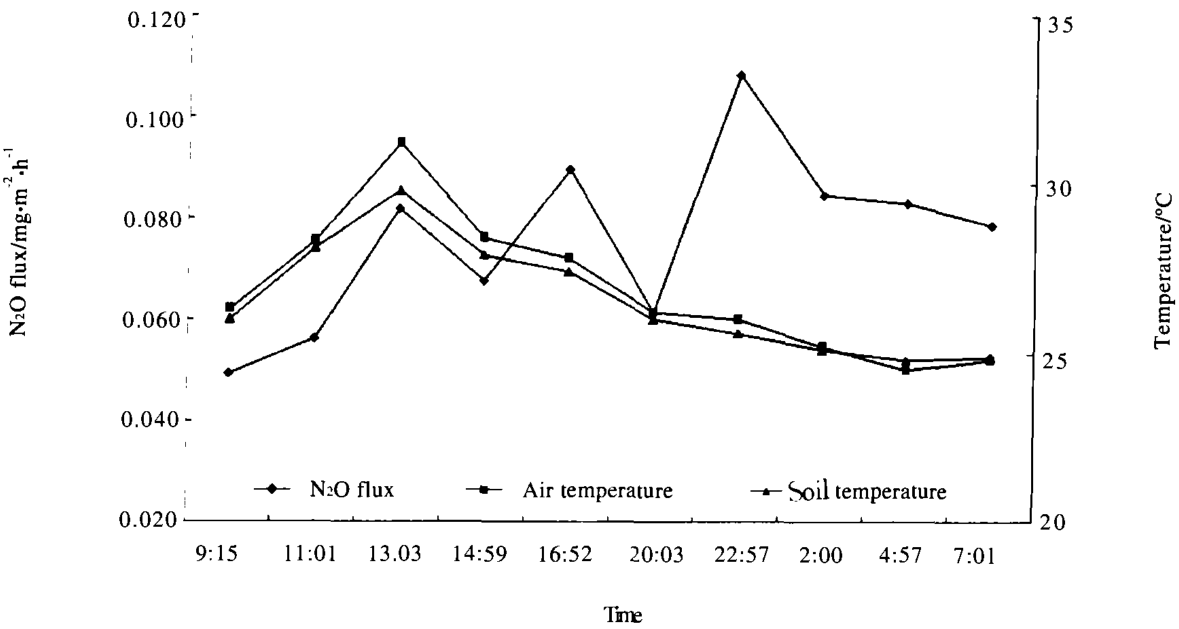


**Figure 3. Diurnal variations of $N_2O$ flux, air temperature and soil temperature**

emitted $N_2O$ to nitrogen ($N_2O/N_2$) shows an inverse relationship with the temperature (Keeney, et al, 1979). Namely, in the process of denitrification, the higher the temperature was, the more the $N_2$ produced, and the less the $N_2O$ produced. Therefore there is also an inverse correlation between $N_2O$ emission flux and the temperature.

## 2.2 Comparison of Gas Fluxes under Different Treatments

In order to study the influences of litter and seedlings on the emissions or absorptions of $CO_2$, $CH_4$ and $N_2O$, three treatments were set in the experimental plot as mentioned above. It was found out that the effect of litter on $CO_2$ flux was the most significant as shown in Table 1.

**Table 1. $CO_2$ fluxes of different treatments at different time**

mg/(m$^2$·h)

| Time | L+S+P | L+S | S |
|---|---|---|---|
| 09:00 | 552.15(33.38) | 549.25(65.55) | 325.92(20.02) |
| 11:00 | 738.32(34.15) | 632.68(53.71) | 427.14(47.81) |
| 13:00 | 693.25(31.81) | 700.57(84.29) | 503.66(73.35) |
| 15:00 | 577.50(82.51) | 611.12(84.90) | 485.73(143.14) |
| 17:00 | 703.87(81.37) | 584.81(41.63) | 446.55(58.13) |
| 20:00 | 577.16(72.46) | 591.62(122.81) | 371.78(87.95) |
| 23:00 | 562.26(37.70) | 569.75(62.65) | 410.82(77.06) |
| 02:00 | 665.49(12.97) | 572.60(80.15) | 439.68(46.06) |
| 05:00 | 520.84(34.66) | 528.61(28.93) | 315.77(29.44) |
| 07:00 | 594.20(19.16) | 488.99(79.39) | 271.90(16.59) |

L + S + P=litter + soil + plant, L + S=litter + soil, S=soil ; SE in parentheses.

Among the three treatments, $CO_2$ flux under S treatment was the lowest in the whole day. Result of variance analysis of the $CO_2$ fluxes under L+S treatment and S treatment indicated that $CO_2$ fluxes under the two treatments differed significantly ($F = 52.63$, $P<0.05$). The difference between $CO_2$ fluxes under the L+S and S treatments could be considered the $CO_2$ emitted from litter, the daily average of which was 183.10 mg/(m$^2$·h), accounting for 31.14% of the average daily $CO_2$ flux under L+S treatment. The ratio of litter $CO_2$ flux to total $CO_2$ flux from forest floor would change with season because the litter input and litter decomposition rate in this type of forest differed greatly in different seasons (Zhang Deqiang, et al, 2000). The variance analysis of the $CO_2$ fluxes under L+S+P treatment and L+S treatment showed that they had not significant difference, the reason of which might be that the plants in the measurement site were too young to respire adequate $CO_2$ that can be detected.

As far as $CH_4$ and $N_2O$ fluxes concerned, there were not significant differences among the three treatments, indicating that litter and seedling had no distinct impact on $CH_4$ and $N_2O$ fluxes in the measurement day. Although it was reported that some kinds of forest plants may emit $N_2O$ under natural circumstances (Xu Hui, et al, 2001; Zhang Xiujun, et al, 2002), the emission was largely dependent on the speices, development stage of the speices and ambient environmental factors (Zhang Xiujun, et al, 2002). As the species in the treatment of L+S+P differed in the sampling sites, the results of this measurement could not prove whether the seedlings in this type of forest was a source of $N_2O$ or not. It was reported that litter and humus affected the soil-atmosphere exchange of the three kinds of greenhouse gases greatly (Dong Yunshe, et al, 1996). But the forest in his study is located in Germany, litter layer of which is much thicker than that in this study owing to its lower ambient temperature and litter decomposition rate, therefore litter's effect on $CH_4$ and $N_2O$ fluxes in the study area is not as distinct as in Germany temperate forest.

By comparing the daily fluxes averages and fluxes measured within 9:00 −11:00 a.m.of the three kinds of greenhouse gases, it was found that the fluxes of $CO_2$ and $N_2O$ measured within 9:00 −11:00 a.m. were significantly different from their daily averages. Therefore, caution must be taken if the $CO_2$ and $N_2O$ fluxes measured within 9:00 −11:00 a.m. are used for extrapolation.

## 3 CONCLUSIONS

(1) Compared with the daily variations of the fluxes of the three kinds of greenhouse gases ($CO_2$, $CH_4$, $N_2O$) from soil surface in other natural ecosystems, which had been reported in China, the daily variation of the fluxes from the mixed forest soil surface in Dinghushan is smaller.

(2) Emission of $CO_2$ from the decomposition of the litter accounted for about one third of the total emission from the soil surface in the measurement day, indicating that litter is an important source of $CO_2$ in this forest.

(3) The fluxes of $CO_2$ and $N_2O$ measured within 9:00 −11:00 a.m. are significantly different from their respective daily averages. It can be derived that the correlations to be applied for calculating daily averages of $CO_2$ and $N_2O$ emissions from the weekly measurements should be taken within 9:00 −11:00 a.m.

## REFERENCES

Dong Yunshe, Qi Y C, Luo J, et al. 2003. Experimental study on $N_2O$ and $CH_4$ fluxes from the dark coniferous forest zone soil of the Gongga mountain, China. Science in China, 46 (3): 285~295

Dong Yunshe, Zhang S, Qi Y C, et al. 2000. Fluxes of $CO_2$, $CH_4$ and $N_2O$ from a typical temperate grassland in Inner Mongolia and its daily variation. Chinese Science Bulletin, 45 (17): 1590~1594

Dong Yunshe, Peng Gangbin, Li Jin. 1996. Seasonal variations of $CO_2$, $CH_4$ and $N_2O$ fluxes from temperate forest soil. Acta Geographica Sinica, 51(suppl.): 120~128

Du Rui, Wang Gengchen, Liu Guanren, et al. 1998. The study on diurnal variation in greenhouse gas revenue and expenditure fluxes of *Leumus chinensis* grassland of Inner Mongolia. Acta Agrestia Sinica, 6 (4): 258~264

IPCC. 2001.Climate change 2001: Impact, adaptation and vulnerability. Cambridge: Cambridge University Press

IPCC. 1995. Climate change 1994. Cambridge: Cambridge University Press

Keeney D R, Fillery I R, Marx G P. 1979. Effect of temperature on gaseous N-products of denitification. Soil Sci Soc Am J, 43:1124~1128

Liu Yunfeng, Ouyang Hua, Cao Guanming, et al. 2001. Soil carbon emission from ecosystems of eastern Qinghai-Tibet Plateau. Journal of Natural Resources, 16 (2): 152~160

Sun Xiangyang. 2000. $CH_4$ emission flux of forest soils in lower mountain area, Beijing. Soil and Environmental Sciences, 9 (3): 173~176

Wang Mingxin, Li Jing, Zheng Xunhua. 1998. Methane emission and mechanisms of methane production, oxidation, transportation in the rice fields. Scientia Atmospherica Sinica, 22 (4): 600~612

Wang Yuesi, Ji Baoming, Wang Mingxin, et al. 2000. Measurement of the exchange rate of greenhouse gases between field and atmosphere in semi-arid grassland. Environmental Science, 21 (3): 6~10

Xu Hui, Zhang Xiujun, Han Shijie. 2001. $N_2O$ emission by trees under natural condition. Environmental Science, 22 (5): 7~11

Zhang Deqiang, Ye Wanhui,Yu Qingfa, et al. 2000. The litter-fall of representative forests of successional series in Dinghushan. Acta Ecologica Sinica, 20 (6): 938~944

Zhang Xiujun, Chen Guanxiong, Xu Hui. 2002. $N_2O$ emission from trees under different light irradiances. Chinese Journal of Applied Ecology, 13 (12): 1563~1565

Zhang Xiujun, Xu Hui, Chen Guanxiong. 2002. $N_2O$ emission rate from trees. Acta Phytoecologica Sinica, 26 (5): 538~542

Managing editor: YUAN Yisheng