EFFECTS OF ARTIFICIAL NITROGEN AND PHOSPHORUS DEPOSITIONS ON SOIL RESPIRATION IN TWO PLANTATIONS IN SOUTHERN CHINA

YS Cao[1, 2], YB Lin[2], XQ Rao[2] & SL Fu[2, *]

[1]*School of Life Science, Jinggangshan University, Ji'an, 343009, China*
[2]*South China Botanical Garden, the Chinese Academy of Sciences, Guangzhou, 510650, China*

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CAO YS, LIN YB, RAO XQ & FU SL. 2011. Effects of artificial nitrogen and phosphorus depositions on soil respiration in two plantations in southern China. In the present study, atmospheric nitrogen (N) and phosphorus (P) depositions were simulated with NH_4NO_3 and KH_2PO_4 solutions respectively to investigate the effects of N and P depositions on soil respiration in two plantations in southern China. The annual soil respiration rate under the control plot was 3190 ± 39.4 g CO_2 m^{-2} and in the *Acacia mangium* and *Eucalyptus urophylla* plantations, the rate was 5180 ± 72.2 g CO_2 m^{-2}. Results of the field experiment showed that both N and P treatments promoted soil respiration rates under *A. mangium* but significantly decreased the soil respiration under *E. urophylla*. The lower level (5 ppm) P treatment significantly enhanced soil respiration rates in *A. mangium* and *E. urophylla* plantations. However, with the increase in P concentration, the soil respiration rates decreased under *A. mangium* but increased under *E. urophylla*. Soil respiration rates exhibited significant fluctuation and approached to nearly equal values at the end of the experiment.

Keywords: Simulation, forest ecosystem, catchment, *Eucalyptus urophylla*, *Acacia mangium*

CAO YS, LIN YB, RAO XQ & FU SL. 2011. Kesan mendapan nitrogen dan fosforus tiruan terhadap respirasi tanah di dua ladang di selatan China. Dalam kajian ini, nitrogen (N) atmosfera serta fosforus (P) atmosfera disimulasi masing-masing menggunakan larutan NH_4NO_3 dan KH_2PO_4. Tujuannya adalah untuk menyiasat kesan mendapan N dan P terhadap respirasi tanah di dua ladang di selatan China. Kadar respirasi tanah tahunan di plot kawalan ialah 3190 ± 39.4 g CO_2 m^{-2} sementara di ladang *Acacia mangium* dan *Eucalyptus urophylla*, nilainya ialah 5180 ± 72.2 g CO_2 m^{-2}. Keputusan kajian di lapangan menunjukkan bahawa N dan P meningkatkan kadar respirasi tanah di ladang *A. mangium* tetapi mengurangkan dengan ketara respirasi di ladang *E. urophylla*. Rawatan P yang lebih rendah (5 ppm) meningkatkan dengan ketara kadar respirasi tanah di ladang *A. mangium* and *E. urophylla*. Bagaimanapun peningkatan kepekatan P menyebabkan kadar respirasi tanah di ladang *A. mangium* menurun. Namun kadarnya meningkat di ladang *E. urophylla*. Kadar respirasi tanah dalam semua rawatan menunjukkan kadar turun naik yang ketara tetapi pada akhir ujian, kadarnya menjadi hampir sama.

INTRODUCTION

With the intensification of the agricultural activity and combustion of fossil fuels, the quantity of nitrogen (N) that is deposited onto the surface of the earth via wet deposition reached 5–14 × 10^{12} g N in 1998 (Holland et al. 1999). Furthermore, as sources and distribution of N compounds are rapidly expanding, N deposition has become a global environmental problem (Mattson et al. 1999, Galloway et al. 2002). It was reported that rates of atmospheric N deposition in forests in the north-eastern USA have remained essentially constant over the past two decades, ranging from < 30 kg ha^{-1} $year^{-1}$ in remote forests to > 40 kg ha^{-1} $year^{-1}$ in high elevation sites downwind of industrial or agricultural areas (Lovett et al. 1982, NADP 2002, Venterea et al. 2003). There are high levels of N deposition in some areas of China as well. The levels of N wet deposition are 8.89 kg ha^{-1} $year^{-1}$ in Xishuangbanna tropical seasonal forest (Sha et al. 2002) and 38.4 kg ha^{-1} $year^{-1}$ in Dinghushan Nature Reserve (Zhou & Yan 2001). The deposition rate was higher in Dagangshan plantations (~61 kg ha^{-1} $year^{-1}$) in middle subtropics (Ma 1989). China became one of the three focal areas of N deposition in the world (Holland et al. 1999, Fang et al. 2006, 2011). Therefore, it is very urgent

*Author for correspondence. E-mail: sfu@scbg.ac.cn

to investigate the effect of N deposition on the forest ecosystem in China.

Carbon storage in global terrestrial soil is about 1500–1600 Pg C, which is three times of that in its vegetation (Schlesinger 1997), and plays an important role in global C sequestration. Soil respiration is the principal pathway for the carbon stored in soil to be emitted to the atmosphere in the form of CO_2. Several values of the total quantity of global soil respiration have been reported, e.g. 100 (Musselman & Fox 1991), 68 (Raich & Schlesinger 1992) and 77 Pg C year^{-1} (Raich & Potter 1995). Thus, understanding the effects of controlling factors on soil respiration is critical because relatively small changes in soil respiration rates may dramatically alter atmospheric concentrations of CO_2 as well as the rates of soil C sequestration. Many studies have shown that soil respiration is influenced by a number of factors such as substrate quality, soil temperature, soil moisture, root biomass, and microbial biomass and activity. The availability of N in soil is considered a controlling factor restricting the net primary production of most temperate ecosystem, but this has not been tested in subtropical and tropical ecosystems. Enhanced N to the ecosystem increases the quantity and activity of microorganisms and thus increases soil respiration. Studies carried out in temperate forests have shown that N additions to forest soils had variable effects on soil CO_2 effluxes, including increased, decreased or unchanged rates (Burton et al. 2004). However, the effects of N deposition on plantations in southern China are rarely studied although plantations are a major type in China due to the huge demand for wood products.

The long-term chronic N deposition has reduced N limitation in forest stands especially in areas of high deposition (Fenn et al. 1998). This process is likely accompanied by changes in phosphorus (P) availability and demand (Gradowski & Thomas 2006). Although P is one of the most important plant macronutrients, the biological and geochemical sinks usually limit its availability in the mineral soil (Wardle et al. 2004). Soil acidification and inhibition of organic mineralisation associated with atmospheric N deposition are likely to further limit the availability of inorganic forms of P (Compton & Cole 1998), which can potentially induce P limitation in the affected ecosystems.

In the present study, two plantations (*Acacia mangium* and *Eucalyptus urophylla*) in southern China were chosen to investigate their response to N and P depositions with a focus on soil respiration processes. *Acacia mangium* is a legume and its rhizospheres can stimulate more growth of rhizobia than the rhizospheres of non-legumes. Therefore, the forest would be possibly limited by P but not N. *Eucalyptus urophylla* is a non-legume but fast-growing species whose growth might be limited by nutrients such as N and P. The concentration of N in the soil was higher than that in *E. urophylla* (Table 1). Consequently, we hypothesised that the addition of N would depress the soil respiration in *A. mangium* stand but vice versa for P.

MATERIALS AND METHODS

This study was conducted at the Heshan Interdisciplinary Experimental Station (112° 54' E, 22° 41' E), Chinese Academy of Sciences in Guangdong Province, China. The climate of the region is subtropical monsoon with mean annual precipitation of 1800–2000 mm, falling mainly in April till September. The period from October till January is particularly dry. The mean annual temperature is 21.7 °C with a mean monthly maximum temperature of 28.7 °C occurring in July and a mean monthly minimum of 13.1 °C in January.

Table 1 Physical and chemical properties of soil in *Acacia mangium* and *Eucalyptus urophylla* plantations

	pH	OM (g kg^{-1})	Total N (g kg^{-1})	Total P (g kg^{-1})	NO_3^--N (mg kg^{-1})	NH_4^+-N (mg kg^{-1})	Available P (mg kg^{-1})
Acacia mangium	4.12 (0.02)	29.32 (1.54)	1.28 (0.16)	0.20 (0.01)	2.94 (0.13)	12.11 (1.37)	1.69 (0.22)
Eucalyptus urophylla	4.18 (0.05)	25.16 (0.17)	0.10 (0.01)	0.02 (0.001)	2.34 (0.11)	10.12 (1.13)	1.40 (0.11)

Data in parentheses denote standard errors; OM = organic matter

The experimental area which is on oxisol soils developed from sandstone has low hills (elevation up to 98 m) and small catchments. A different forest type was randomly allocated to each catchment and trees were planted at 2.5 × 3 m spacing. Five catchments are single species stands of *A. mangium*, *A. auriculiformis*, *E. urophylla*, *Pinus elliottii* and *Schima superba*, and one, a mixed forest of legumes including *A. mangium*, *A. confusa* and *A. holosericea*. Our study was conducted in *A. mangium* and *E. urophylla* plantations in two separate catchments.

Six soil samples were drilled in each plantation for analyses of soil physical and chemical properties. Concentrations of the available and total P were determined with acid melt-molybdenum stibium anti-colour method. The concentration of the total N was determined with semi-micro Kjeldahl method, NH_4^+-N with indophenol blue method and NO_3^--N with diazotisation coupling technique (Liu et al. 1996). Soil organic matter was determined using the potassium dichromate method (Liu et al. 1996).

Field experiment

Nine plots (10 × 10 m each) were randomly chosen for each treatment of N (5 g N m^{-2} $year^{-1}$), P (1.0 g P m^{-2} $year^{-1}$), N + P (5 g N m^{-2} $year^{-1}$ + 1.0 g P m^{-2} $year^{-1}$) and an untreated control. Nitrogen treatment was added as NH_4NO_3 and P treatment as KH_2PO_4 solutions. Each application was dissolved in 20 litres water and delivered via a backpack sprayer to the floor of the forests. During this study, control plots received an equivalent application of water only. Before treatments of N and P, six soil samples were sampled in each plantation for determining physical and chemical properties. Five soil cores were mixed into one composite sample. The N and P simulation treatments were conducted on April 2007 to August 2008.

The dynamic chamber technique was used to determine soil respiration rates in the field. Three collars were embedded into each plot and three chambers (20 cm in diameter, 20 cm in height for each chamber) were fitted into the collars when measurements were made. The chambers were then sealed with water. Gas samples were taken with syringes (100 ml in volume) at an interval of 30 min and four samplings were done in order to calculate the rates of soil respiration.

Laboratory experiment

Soil samples were taken from *A. mangium* and *E. urophylla* plantations and air dried in the laboratory and plant roots were removed by hand. An amount of 3 kg soil from each plantation was placed in a polyvinyl chloride (PVC) chamber (diameter 20 cm and height 60 cm) which was used as an incubator. The incubator was then hermetically sealed with cap nuts at the top and bottom. The headspace height of the chamber was 30 cm after soil samples were filled. A tube was installed at the top of one side of the chamber for gas sampling. Seven treatments, namely, control, N_{50}, N_{100}, N_{150}, P_5, P_{10} and P_{15} were set up and there were three replications for each treatment. NH_4NO_3 with concentrations of 35.46, 76.92 and 115.38 mg N kg^{-1} was added for N treatments (N_{50}, N_{100}, N_{150} respectively) and KH_2PO_4 with concentrations of 3.85, 7.69 and 11.54 mg P kg^{-1} for P treatments (P_5, P_{10} and P_{15} respectively) to simulate atmospheric N deposition at levels of 50, 100, 150 kg N ha^{-1} $year^{-1}$ and P deposition at the levels of 5, 10 and 15 kg P ha^{-1} $year^{-1}$. The control plots received the same amount of water without additional N or P. The moisture content in all treatments was controlled at 40% of soil water holding capacity (WHC) by weighing. All gas samples were taken using 100 ml syringes at intervals of 30 min. The N and P simulation treatments were conducted from December 2007 till January 2008.

All gas samples were analysed with gas chromatography. The following formula was used to calculate the flux of CO_2:

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

where F and D are the flux and density of gas respectively; V, A and h are the volume, area and height of the chamber respectively; and $\frac{\Delta m}{\Delta t}$ is the slope of density with time.

We used repeated-measures one-way analysis of variance (ANOVA) to determine the influence of time and N and P depositions on CO_2 flux. A Fisher's protected least significant difference (LSD) was used to compare means, and significance for analyses was accepted at $\alpha = 0.05$.

RESULTS

Soil respiration rates determined in the field

The soil respiration rates in all treatments were marginally higher than the control in *A. mangium*, but significantly lower than control in *E. urophylla* ($p < 0.05$, Table 2). Results showed that N and P treatments promoted the release of CO_2 from the soil in *A. mangium* but depressed it in the *E. urophylla* plantation. Furthermore, it could be concluded that the soil respiration rates in *A. mangium* were lower than those in *E. urophylla*.

The soil respiration in *A. mangium* fluctuated with time which peaked in May and was lowest in January (Figure 1a). The variation patterns of soil respiration in *E. urophylla* (Figure 1b) were similar to *A. mangium*. In general soil respiration rates in all treatments in both plantations were higher in the rainy season than in the dry season. Soil respiration rates in the control plots ranged from 153.3 to 609.5 mg CO_2 m^{-2} $hour^{-1}$ in *A. mangium* and 162.2 to 925.8 mg CO_2 m^{-2} $hour^{-1}$ in *E. urophylla*.

Soil respiration rates determined in the laboratory

The mean soil respiration rates in the N_{50} (151.1 ± 7.1 mg m^{-2} $hour^{-1}$) and N_{100} (171.8 ± 2.6 mg m^{-2} $hour^{-1}$) treatments in *A. mangium* were significantly ($p < 0.05$) higher than the control (Figure 2a). However, the soil respiration rate in N_{150} which had the highest concentration of N was lower than that in the control, with no significant treatment effect. Soil respiration rate in N_{50} treatment in *E. urophylla* was significantly higher than the control ($p < 0.05$). However, soil respiration rates in N_{100} and N_{150} were lower than the control in *E. urophylla*. Moreover, the soil respiration rate decreased with the increase of N concentration in treatments (Figure 2a).

The soil respiration rate in the lowest P treatment (P_5) was significantly higher than the control in *A. mangium* (Figure 2b). However, the soil respiration rates decreased with the increase of P concentration in treatments, and were lower both in P_{10} and P_{15} treatments than that in the control. In contrast, soil respiration rates were significantly lower in the P_5 treatment but were significantly higher ($p < 0.05$) in P_{15} treatment than that in the control in *E. urophylla* (Figure 2b). The mean soil respiration rates in *E. urophylla* stand increased with the increase of P concentration in treatments.

DISCUSSION

Variation of soil respiration

The mean soil respiration rates in the control in *A. mangium* and *E. urophylla* were 364 and 591 mg m^{-2} $hour^{-1}$ respectively. Based on the annual mean value of CO_2 flux in the control, we estimated the annual soil CO_2 emissions from soil surface in *A. mangium* and *E. urophylla* and they were 3190 and 5180 g CO_2 m^{-2} $year^{-1}$ respectively. The annual CO_2 fluxes from tropical forest soils are 3316 g m^{-2} $year^{-1}$ in Jianfengling, tropical China (Wu et al. 1997) and 4982.3 g m^{-2} $year^{-1}$ in Brazil evergreen forest (Goreau & Mello 1988). The annual mean value of CO_2 fluxes in the monsoon forest dominated by *Cryptocarya concinna* and *Castanopsis chinensis*, the coniferous and broad-leaved mixed forest, and *Pinus massoniana* forest in Dinghushan Biosphere Reserve in the subtropical China were 4169, 3509, 2210 g m^{-2} $year^{-1}$ respectively (Zhou et al. 2005). Soil respiration rate in *Phyllostachys pubescens* plantation in mid-subtropical zone of China was 3077 g m^{-2} $year^{-1}$ (Huang et al. 1999). The annual soil CO_2 flux of temperate forests of *Betula platyphylla*, *Quercus liaotungensis* and *Pinus tabulaeformis* in China were 1132, 1431 and 866 g m^{-2} $year^{-1}$ respectively (Liu et al. 1998). Results in the present study illustrated that the CO_2 fluxes from plantations in our study site fell into the range of those in tropical and subtropical forests but much higher than those from temperate forests.

Table 2 The mean soil respiration rates in *Acacia mangium* and *Eucalyptus urophylla* plantations

	Control	N	P	N + P
A. mangium	364.17 (39.40)	380.41 (40.98)	386.45 (41.67)	389.54 (47.89)
E. urophylla	591.33 (72.21)	439.84 (60.19)	435.56 (51.97)	422.44 (49.65)

Data in parentheses denote standard errors

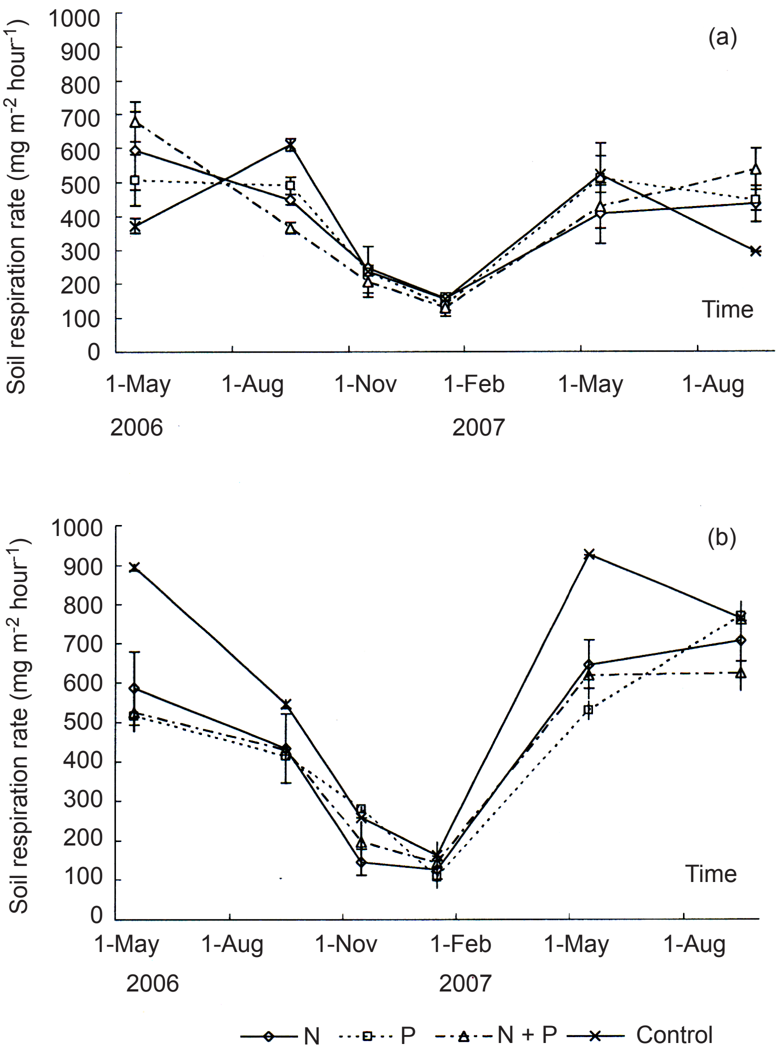

Figure 1 Seasonal variations of soil respiration determined in the field of (a) *Acacia mangium* and (b) *Eucalyptus urophylla* plantations after additions of N (5 mg kg^{-1}) and P (1.0 mg kg^{-1}). The bars represent standard errors (n = 3).

Interaction of soil nutrients modulates soil respiration

Results from our field experiment showed that N and P treatments promoted the release of CO_2 from the soil in *A. mangium* but depressed it in the *E. urophylla* plantation. The results of laboratory experiment showed that the lower level N treatment promoted soil respiration in *A. mangium* as well. Soil respiration is the total CO_2 fluxes which include the respiration of roots and microbial. Thus, the response of soil respiration to N and P additions may also be affected by the activity of plant roots. We found that there was abundant understory species under *A. mangium* but little under *E. urophylla*. The addition of N would promote the growth of these understory species and enhance root respiration and consequently, the total soil respiration.

The results of laboratory experiment showed that the lowest N addition (N_{50}) enhanced soil respiration but depressed it when N concentration increased in *E. urophylla*. Moreover, the soil respiration rate decreased with the increase of N concentration in treatments (Figure 2a). However, the mean soil respiration rates in *E. urophylla* stand increased with the increase of P concentration in treatments. Thus, N deposition may have turned the N-limited forest ecosystem in subtropical China to a P-limited forest.

The decomposition of plant litter is a major source of soil CO_2 efflux. The content of available N in soil is the main factor affecting decomposition of plant litter, and litter decomposition rate would increase when soil N availability is enhanced. However, when the concentration of N in soil becomes excessive, the nutrient balance would be disrupted and the availability of other nutrient

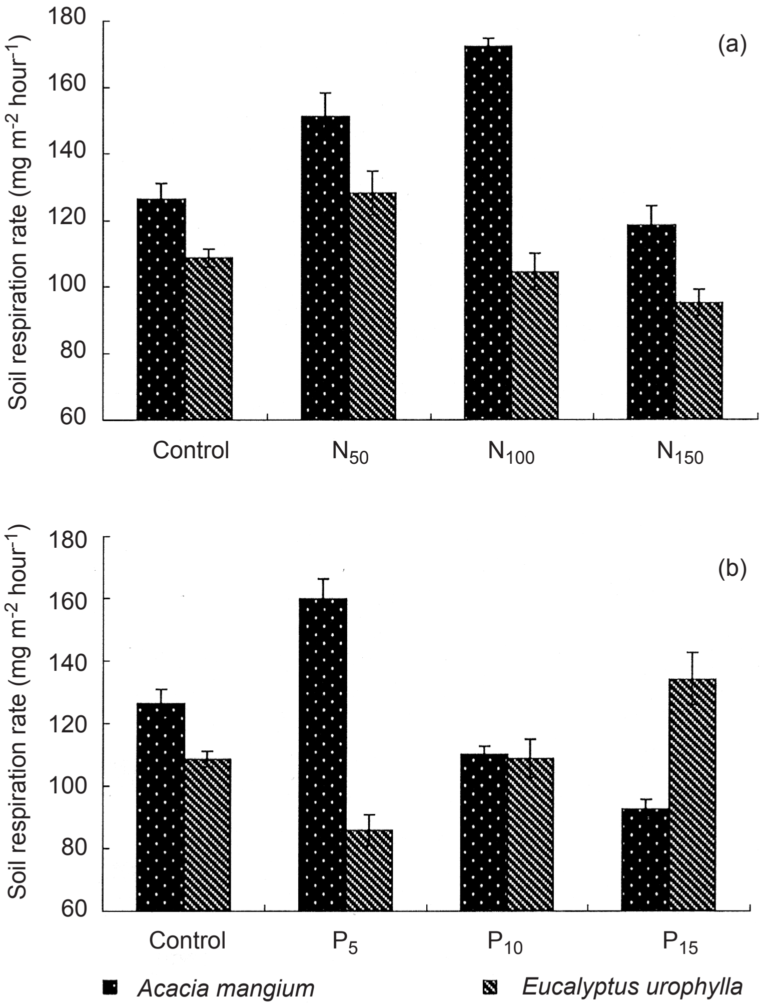

Figure 2 Mean soil respiration rates of *Acacia mangium* and *Eucalyptus urophylla* determined in laboratory with treatments of various levels of (a) N and (b) P concentrations. N_{50}, N_{100}, N_{150} refer to N treatments at levels of 50, 100 and 150 kg N ha^{-1} $year^{-1}$ respectively and P_5, P_{10} and P_{15} refer to P treatments at levels of 5, 10 and 15 kg N ha^{-1} $year^{-1}$ respectively. Bars indicate standard errors (n = 3).

elements would be reduced, thereby inhibiting litter decomposition. It was reported that N deposition promoted the decomposition of *Pinus massonania* litter only in the early stages (Mo et al. 2004) but had no significant effect on the decomposition of *S. superba* litter. Other studies also demonstrated that the effects of N and P depositions on the decomposition of plant litter and soil organic material were different at different stages of decomposition (Berg & Matzner 1997). NH_4^+ and NO_3^- added to fresh litter will promote the decomposition of cellulose and soluble substances at the early stages but inhibit significantly the decomposition of humus (Berg & Matzner 1997). N addition experiments performed in temperate forests showed that most of the N which entered the forest ecosystems by atmospheric deposition was retained in the soil, mainly in soil organic matter (Nadelhofer et al. 1999). N treatments could change the release of C in the humus, thereby affecting the interaction of C and N cycling in forest ecosystems (Bowden et al. 2004). Our results demonstrated that the interaction of different soil nutrient elements played an important role in modulating soil respiration.

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