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Investigation of in situ soil nitrogen mineralization in a Picea-Abies forest on the Tibet Plateau: effects of increased nitrogen input

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Abstract

The main objective of this study was to quantify the dynamics of ammonium (NH_4^+) and nitrate (NO_3^-) in the humus (0-7cm) and the uppermost mineral layer (0-15cm) of a forest soil. The soil was treated annually from 2012 to 2013 with one single dose of nitrogen (0, 15, 30kg N $ha^{-1}yr^{-1}$ applied as $(NH_4)_2SO_4$, NH_4Cl, KNO_3). Net N mineralization, including net ammonification and net nitrification was determined in four in situ incubation periods over 2 years in a Picea-Abies forest stand at the Qinghai-Tibet Plateau, Southwest China. Measurements were done using soil cores (7cm or 15cm deep) with a resin bag filled with combined anion and cation exchange resins placed at the base to collect the N leaching from the soil. The accumulation rate of N was corrected for both deposition and fertilizer N inputs. In all treatments, both the content and accumulation of the mineral N were dominated by NH_4^+ which accounts for about 76-89% of the net mineralization. The accumulation rate of N decreased to 64-83% in KNO_3 treatments. The net N mineralization rate increased with nitrogen input, especially in NH_4^+-N treatments (p<0.05). However, this promoting role decreased over time. At the highest $(NH_4)_2SO_4$ additions, the net ammonification and net mineralization rate increased notably in the humus (0-7cm) rather than in the uppermost mineral layer (0-15 cm). Previous studies that reported on soil net mineralization from forests under different environmental conditions were compiled and assessed for the effects of atmospheric N deposition and environmental factors, annual precipitation, and annual temperature on annual fluxes of net nitrogen mineralization in forest soils, worldwide. The results show that an increase in atmospheric N deposition significantly enhances the soil net nitrogen mineralization rate. Variation in atmospheric N deposition accounts for 48% of the variation in the rate of soil net nitrogen mineralization across the forests.

1. INTRODUCTION

The mineralization level of organic nitrogen is an important indicator of soil nitrogen supplying capacity (BURTON et al., 2007). It also influences the circulation rate of soil nitrogen and the productivity level of a forest (OUYANG et al., 2008). There is a correlation between atmospheric nitrogen deposition, soil nitrogen transformation, and nitrogen leaching (VESTGARDEN et al., 2003; SULTANA et al., 2004; BRENNER et al., 2005). Atmospheric nitrogen deposition can also influence the mineralization and nitrification rate of forest soil nitrogen which can lead to nitrogen loss (ABER & MAGILL, 2004; MCNULTY et al., 2005) and nitrogen storage change (DAVID et al., 1998).

Some research shows that an increase in simulated nitrogen deposition promotes the net mineralization flux of forest soil nitrogen (VESTGARDEN et al., 2003; BRENNER et al., 2005) in the early phase of the experiment, but such promotion weakens gradually over time (MAGILL et al., 1996; MAGILL et al., 2000). Alternatively, other research shows that nitrogen deposition increase inhibits (JUSSY et al., 2004) or does not influence (EMMETT et al., 1995; GUNDERSEN et al., 1998) the net mineralization flux of forest soil nitrogen. In view of this, it is necessary to further the current understanding of the effects of nitrogen deposition increase on the net mineralization flux of forest soil nitrogen. This will help to predict the characteristics of the soil nitrogen transformation fluxes in forest ecosystems of different areas and the response to future atmospheric nitrogen deposition increase.

China is the third largest nitrogen deposition concentration area in the world (RICHTER et al., 2005). However, most of the research on atmospheric nitrogen deposition on forest soil nitrogen behaviours is conducted in laboratories (ZHOU & OUYANG et al., 2001; ZHOU et al., 2003). The dilemma here is that this cannot properly reflect the in-situ soil nitrogen transformation (ARNOLD et al., 2008) unless in-situ studies are conducted. At present, very few in-situ field research activities are underway in China to investigate the effects of atmospheric nitrogen deposition increase on forest soil nitrogen transformation flux. Most of the reported research concerns subtropical/tropical forest ecosystems (MENG et al., 2001; FANG et al., 2004; LI & SHA 2005; CHEN & JAN, 2007). Hence, this cannot be considered enough for a comprehensive assessment of the effects of atmospheric nitrogen deposition on net transformation of forest soil nitrogen in different areas in China. Nevertheless, there are many in situ observations reported in the international literature on net transformation fluxes of temperate forest soil nitrogen. To the best of our knowledge, there is a lack of research on comprehensive assessment of the effects of deposition of different forms of nitrogen, different forest types, and different climatic factors on the net mineralization flux of soil nitrogen.

To address this issue, a comprehensive in-situ investigation of the effects of simulated atmospheric nitrogen deposition increase on net mineralization flux of forest soil nitrogen in a site located in Qinghai-Tibet Plateau forest was conducted over a period of two years. This timely research will help to further our current understanding and the extent of the effects of nitrogen deposition on the net mineralization flux of forest soil nitrogen and the effect of climatic factors on the net mineralization flux of forest soil nitrogen.

2. MATERIALS AND METHODS

2.1. The study area

The study area is located in the comprehensive observation station of the Chinese Academy of Sciences in Nyingchi LuLang town of the Tibet autonomous region (29°46'N, 94°44'E) of the southeast mountain region. The study area has a flat topography with an elevation of 3200 metres above sea level. The Nyingchi area is a typical tropical humid and semi-humid climate affected by The Indian Ocean and the Pacific warm current. It features a short frost-free period (about 170 days throughout the year) and a long frozen period, dry and windy in spring, short and warm summer, cool and foggy autumn, and long and sunny cold winter. The average annual temperature is 12°C. The annual average rainfall is 600-800mm and 92.4% of the rainfall occurs in spring.

The vegetation type is coniferous Picea-Abies forest in the Tibetan plateau. The forest type is a mature virgin forest and the dominant tree species are on average more than 100 years old. The main tree species include: *Abies georgei var. smithii*, *Picea likiangenses var. linzhiensis*, *Pinus yunnanensis* and *Pinus densata*. The soil in this area is a Cambisol.

2.2. Sample collection and analysis

Self-made rain collectors were used to gather penetration rainwater. The rainwater collector consists of a funnel and a collection bottle. According to seasonal changes in rainfall intensity, 2-3 random samplings were made in each month. In total, 16 collectors were evenly placed around the experimental area to capture the regional heterogeneity in precipitation rate at the site. The sampling period was from May to October during 2012 and 2013.

The resin core method proposed by BHOGAL et al. (1999) was used for the in-situ measurement of the net ammonification, net nitrification, and net mineralization fluxes of soil nitrogen. Considering the thickness of soil layer A and fine root system distribution in the forest, the organic-layer soil depth and "full-layer" soil depth were determined as 0-7cm and 0-15cm, respectively. These were used as benchmarks for other observations in order to understand any correlation between soil nitrogen transformation flux and the net fluxes of the soil's surface carbon and nitrogen gases, and also the correlation between soil nitrogen transformation flux and the leaching fluxes of the soil's surface carbon and nitrogen gases.

The field experiments began in July 2012. At first, four sampling points adjacent to each other were selected in each treated quadrat, and two repeated treatments were designed for organic layers and full layers in each sampling points. Then, the surface vegetation was completely cleared off, some PVC pipes (7.0cm in diameter and 7.0cm in height for organic layers, 7.0 cm in diameter and 15.0cm in height for full layers) were driven by a hammer into the soil. The pipes then were carefully removed and soil of 2 cm thick was removed from bottom of the pipes and the remaining soil was then put into the prepared resin bags. Each bag contained 20g of cation-anion exchange resin. Finally, the PVC pipes were buried in the original places. Prior to the experiment, the amount of soil taken from 0-7 cm layer and 0-15 cm layer outside the experimental plot was considered as the initial baseline values of soil nitrogen mineralization. Then, the soil was sampled in September and November 2012 and April, July, and November 2013. After every sampling, new pipes were buried in new places in the experiment plot until the end of the experiment in November 2013. All the samples were sieved and kept frozen for later analysis. Plots of 5m´5m were arranged into three blocks and fertilizer-N was added as annual single doses of $(NH_4)_2SO_4$, NH_4Cl and KNO_3 from 2012. The doses are 0 (control), 15 (low N) and 30 (high N) kg N $ha^{-1}yr^{-1}$.

2.3. Statistical analysis

For the soil samples from two different depths, the net ammonification flux of the soil nitrogen can be calculated as the difference between the NH_4^+-N content in the counterpart soil layers between two adjacent samplings plus the NH_4^+-N content absorbed by the resin. The net nitrification flux of the soil nitrogen is the difference between the NO_3^--N content in the counterpart soil layers between two adjacent samplings plus the NO_3^--N content absorbed by the resin. The net mineralization flux of the soil nitrogen is the sum of the net ammonification flux and the net nitrification flux (HATCH et al., 2000). The monthly forest precipitation nitrogen deposition flux during the field observation period was calculated by multiplying the precipitation volume mean concentration and the precipitation amount.

The total dissolved nitrogen (DN) in precipitation was been determined with a TOC/TN analysis meter (Shimadzu TOC-V_{CSH}/TN). Dissolved organic nitrogen (DON) in precipitation was also calculated based on the difference between the total nitrogen content and the content of mineral nitrogen. The content of NH_4^+-N and NO_3^--N in precipitation, resin, and soil samples was determined by the colorimetric method (KIM, 1995). The unit of nitrogen deposition flux in different forms in precipitation and of flux of mineral nitrogen in resin is mg N m^{-2}.

For all the forest soil nitrogen mineralization fluxes, the average values and standard errors were calculated. A one-way ANOVA method in a t-test provided using software SPSS11.5 was employed to compare the morphological differences among the deposition of nitrogen in its different forms (p<0.05). Factor analysis in SPSS-Data Reduction was conducted to investigate the differences in net ammonification, net nitrification, and net mineralization fluxes of forest soil nitrogen in different years and under various conditions of nitrogen application. Stepwise regression analysis in SPSS-Regression was used to analyze the key factors in soil attributes, average annual temperature, and annual precipitation which influence the net mineralization flux of forest soil nitrogen. With reference to the literature and based on SPSS factor analysis, the key factors influencing annual net mineralization flux of regional forest soil nitrogen were investigated. For all the results obtained, average values and standard errors were calculated.

The annual nitrogen deposition is the sum total of every monthly figure. The unit of nitrogen sediment fluxes of different forms are kg N ha^{-1}. Regression analysis and correlation coefficients between different forms of nitrogen concentrations in wet sediment and atmospheric temperature or precipitation was conducted by the one-way ANOVA of SPSS.

3. Results and discussion

3.1. Change Law of Nitrogen Wet Sediment

Atmospheric temperature and precipitation in the growing seasons during 2011 and 2013 are shown in Figure 1. These two climate factors have significant seasonal variation, the highest in

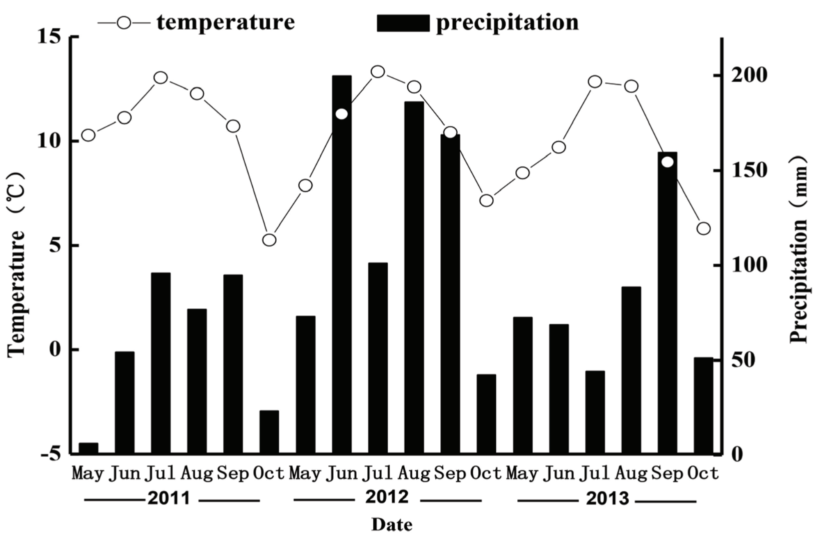

Figure 1. Seasonal changes in atmospheric temperature and precipitation in the forest.

Table 1. Annual changes in different forms of nitrogen content in forest penetration rain.

	NH_4^+-N	NO_3^--N	TIN	TN	NH_4^+-N / TIN	TIN / TN
	kg N $ha^{-1}yr^{-1}$				%	
2012	5.06	2.21	6.92	8.71	73.13	79.46
2013	2.93	0.44	3.38	5.58	86.83	60.48

summer, and the lowest in the spring and autumn. At the same time, there is a big difference in precipitation during each year.

Figure 2. shows different forms of nitrogen (NH_4^+-N, NO_3^--N, TIN (Total Inorganic Nitrogen, TIN), TN (Total Nitrogen, TN)) concentrations in wet sediment flux from May to October in 2012 and 2013. From Figure 1. it can be seen that the atmospheric nitrogen deposition has a significant seasonal change. High values of inorganic N concentration were found in summer; while, low values were observed in spring.

In 2012, NH_4^+-N, NO_3^--N and the total mineral nitrogen in the atmospheric wet sediment of coniferous Picea-Abies forest in the Tibetan area were 5.06, 2.21, and 8.71 kg N ha^{-1} yr^{-1}, respectively. While, the amount of these forms of nitrogen were 2.93, 0.44, and 5.58 kg N ha^{-1} yr^{-1} in 2013 (Table 1), respectively. Ammonium nitrogen is the main proportion of the mineral nitrogen sediment which accounts for about 73-87% of the mineral nitrogen. Mineral nitrogen is the basis of the total nitrogen deposition.

3.2. The effect of simulated nitrogen deposition on the net transformation flux of soil nitrogen in a temperate forest

The variation in annual net mineralization flux of soil nitrogen in the control plot in the spruce-fir forest of the Qinghai-Tibet Plateau from 2012 to 2013 was 5.58-8.71 N kg $ha^{-1}yr^{-1}$ which is lower than that reported by VESTGARDEN et al. (2003) (-7.7 N kg ha^{-1} yr^{-1}), BLUMFIELD et al. (2004) (13.4 N kg ha^{-1} yr^{-1}) and BRENNER et al. (2005) (13.6-29.7 N kg ha^{-1} yr^{-1}). This is also much lower than the annual net mineralization flux of the soil nitrogen in a European coniferous forest reported by SCHROETER et al. (2003) (30-90 N kg ha^{-1} yr^{-1}) and the annual net mineralization flux of the soil nitrogen in a Chinese subtropical forest reported by CHEN & JAN (2007) (62.6 N kg ha^{-1} yr^{-1}). Clearly, the annual net mineralization flux of forest soil nitrogen may vary

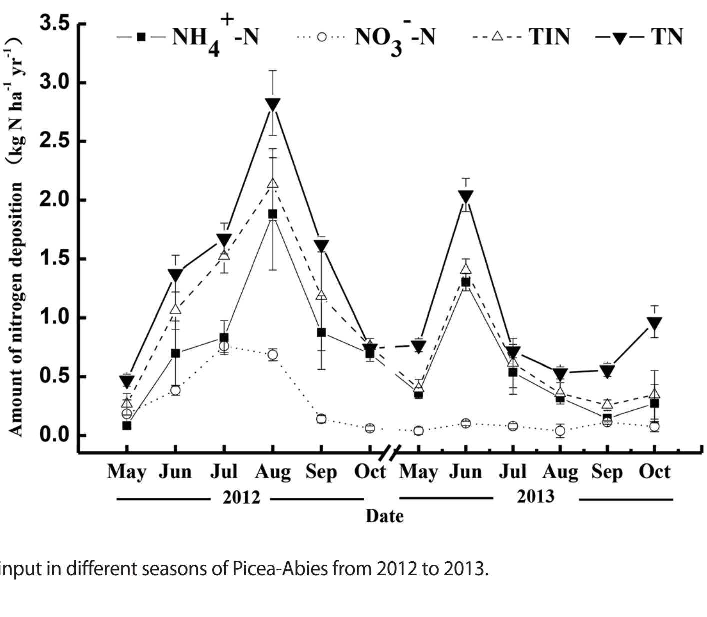

Figure 2. Different forms of nitrogen input in different seasons of Picea-Abies from 2012 to 2013.

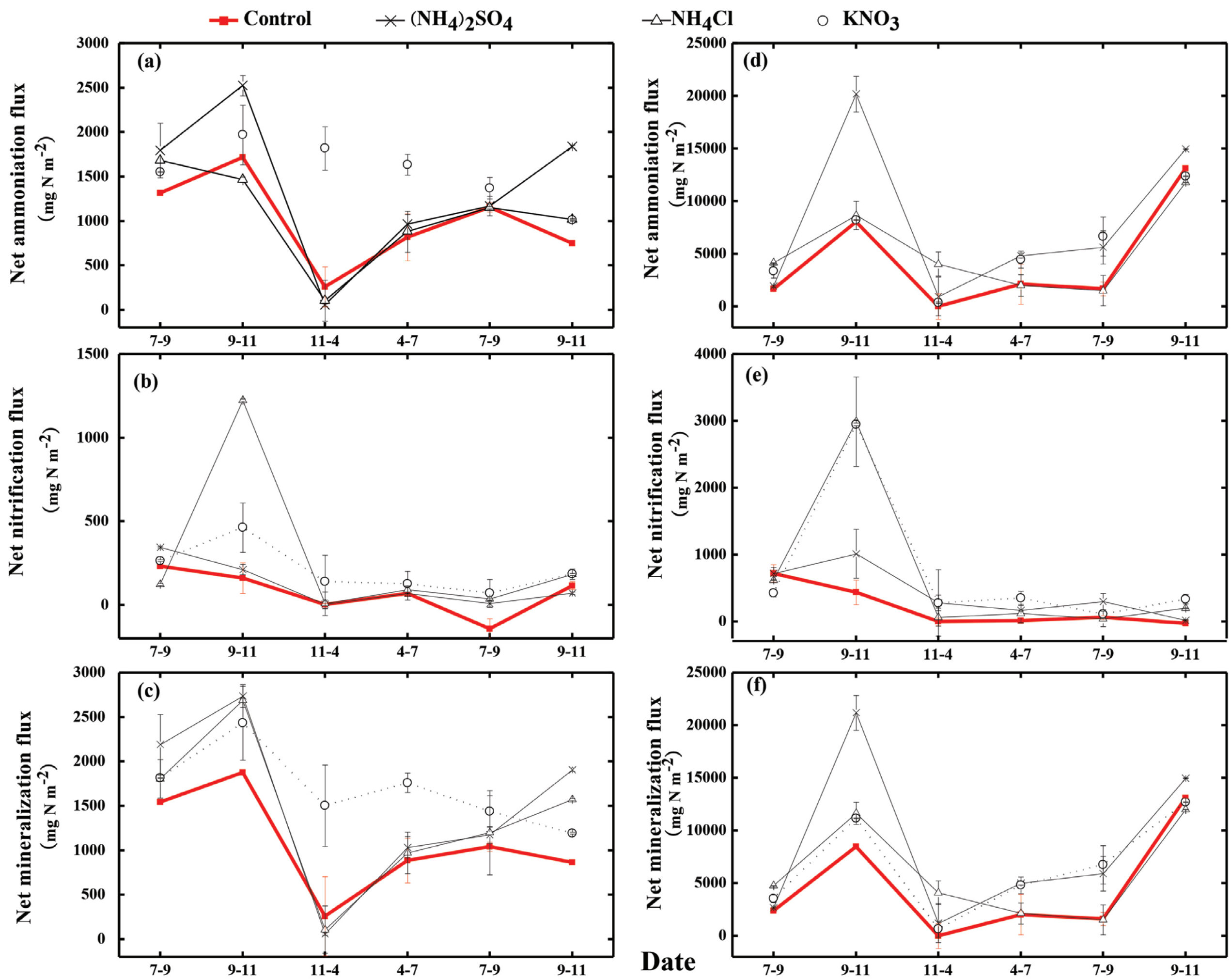

Figure 3. The effect of high nitrogen input on soil net ammonification, net nitrification, and net mineralization in different years. a-c: 0-7cm; d-f: 0-15cm; Error bar is standard error for four repeated measurements.

with different regional atmospheric nitrogen depositions, different soil and forest types, and different experimental methods.

In the field experiment, the control treatment showed that the net ammonification flux, net nitrification flux, and net mineralization flux of the nitrogen in the samples from 0-7cm soil layers and 0-15cm soil layers share similar seasonal variability. To be more specific, the net transformation flux of nitrogen in summers and autumns of 2012 and 2013 was a little higher than that in the springs and winters of the same years; but, the difference was not significant (Figures 3 and 5). In the experimental plot with no nitrogen, the annual net mineralization fluxes of the nitrogen in the 0-15cm soil layers in 2013 were significantly higher than that in 2012 (p<0.05) (Figure-4 and Figure-6). With linear regression analysis, an equation with two unknowns was established to indicate the influence of temperature (T) and precipitation (P) on the net mineralization flux (Y_1) of the nitrogen in the 0-7cm soil layer: Y_1=(3.15±1.18)T+(5.49±7.97)P-(82.91±214.62).(R^2=0.94, n=6, p<0.05) Therefore, according to the regression determination coefficient (R^2), it could be concluded here that the temperature is the key factor influencing seasonal variations in the net transformation flux of forest soil nitrogen (STENGER et al., 1996; PAJUSTE et al., 2003; XU, 2005). KNOEPP & VOSE (2007) reported that in a mixed broadleaf-conifer forest in the Eastern U.S. the monthly accumulative net mineralization flux and monthly accumulative nitrification flux of temperate forest soil nitrogen increased significantly as the soil temperature and humidity rose. The soil temperature had a greater influence on the net mineralization flux of nitrogen and both the soil temperature and humidity were the reason for 83% variation in the net mineralization flux of soil nitrogen. PAJUSTE et al. (2003) pointed out that temperature, humidity, and pH could together explain 70% of the variation in annual net ammonification flux of the soil nitrogen in a Scots pine (*Pinus sylvestris*) and Norway spruce forest of East Estonia of which the net ammonification flux of Scots pine (*Pinus sylvestris*) forest soil nitrogen had a significantly positive correlation with temperature (R^2=0.69, p<0.0001).

The annual net mineralization flux of the fir forest soil nitrogen in Qinghai-Tibet Plateau was mainly manifested by the net ammonification flux which accounts for 76-89% of the net mineralization flux. In 2013, the input of a high dose of KNO_3 significantly inhibited the proportion of net ammonification flux to net mineralization flux of the nitrogen in the 0-7cm soil layer. However, the input of NH_4^+-N did not show any significant influence on the proportion of net ammonification flux to net mineralization flux of the nitrogen in the same soil layer. Earlier research suggests that the nitrogen deposition increase was reduced or did not influence the proportion of net ammonification flux to total net mineralization flux of soil nitrogen. BRENNER et al. (2005) reported that the net ammonification flux accounts for 68.9% of

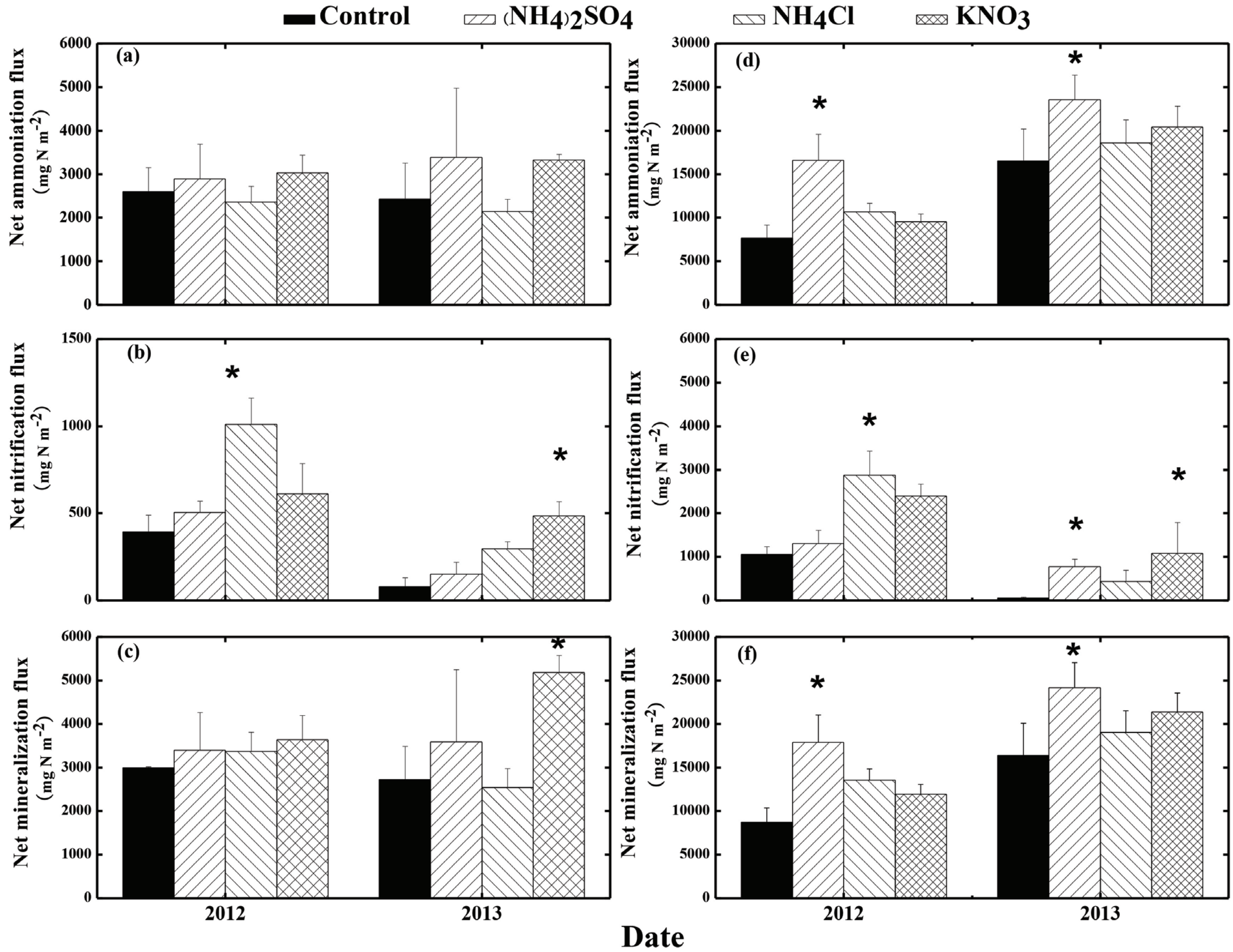

Figure 4. The effect of high nitrogen input on soil net annual nitrogen mineralization in different years. a-c: 0-7cm; d-f: 0-15cm; Error bar is standard error for four repeated measurements.* is significant level with contrast.

the total mineralization flux of the nitrogen in the 0-20cm soil layer in a high-latitude forest in the USA and the input of 100 N kg ha^{-1} yr^{-1} of $NaNO_3$ caused the proportion to decrease to 31%. According to EMMETT et al. (1995), in a forest of the Northern UK, the net ammonification flux accounts for 90% of the net mineralization flux in the 0-7cm soil layer and the input of 35 N kg ha^{-1} yr^{-1} of NH_4NO_3 and the input of 70 N kg ha^{-1} yr^{-1} of NH_4NO_3 caused the proportion to decrease to 85% and 75%, respectively.

At the initial phase of the field experiment, the input of different doses of NH_4^+-N significantly promoted ($p<0.05$) both the annual net ammonification flux and the annual net mineralization flux of the nitrogen in the 0-7cm and the 0-15cm soil layers; especially in the 0-15cm soil layer. The annual net ammonification flux and annual net mineralization flux of the nitrogen in the 0-7cm soil layer in the experiment plot applied with NO_3^--N showed a tendency to increase with the extension of the years of NO_3^--N application compared with the application of NH_4^+-N (see Figure-3 and Figure-5). These results suggest that for the same site conditions, the influences from the input of nitrogen in different forms on forest topsoil nitrogen transformation flux might be different. Previous research showed that a short period (e.g., 1 to 2 years) of simulated nitrogen deposition increase significantly promoted the net mineralization flux of forest soil nitrogen (EMMETT et al., 1995; SULTANA et al., 2004; BRENNER et al., 2005). The 14-year (from 1988 to 2002) simulated nitrogen deposition experiment conducted by MCNULTY et al. (2005) on a redwood forest of the U.S. showed that the increase of NH_4Cl input significantly promoted the net mineralization flux of soil nitrogen in the first four years of the experiment. However, the promotion weakened gradually with the extension of the years of NH_4Cl application. By 1994, the nitrogen mineralization potential of the soil in the plot supplied with nitrogen was lower than that in the control plot and nitrogen deposition increase did not significantly influence the net mineralization flux of the soil nitrogen. It is evident that the increase in nitrogen input, especially NH_4^+-N input, significantly promotes the net mineralization flux of soil nitrogen in a short period (e.g., from 1 to 3 years). However, the promotion gradually weakens with the extension of the years of nitrogen application.

With the increase in nitrogen deposition, the net mineralization flux of soil nitrogen increases accordingly and the contribution rate of nitrogen deposition to net mineralization flux in the temperate old-growth forest is about 25%. MAGILL et al. (2000) conducted a nine-year in-situ observation on the net mineralization flux of soil nitrogen in a mixed broadleaf-conifer forest in the eastern part of Maine (USA). Their results showed that both the input of a low dose (50 N kg ha^{-1} yr^{-1}) and a high dose (150 N kg ha^{-1} yr^{-1}) of NH_4NO_3 significantly promotes the net mineralization flux of soil nitrogen. The promotion by application of the

Table 2. Previous reports on soil net nitrogen mineralization in regional forest ecosystems.

Forest type	Geographic position		pH	C/N	Methods [a]	Soil depth	Nitrogen fertilizers	Deposition	fertilizer	Net mineralization	Net nitrification	years	references
	latitude	longitude											
						(cm)		N kg $ha^{-1}yr^{-1}$					
Picea abies	56°33'N	13°13'E	4.1	29	A	0-5		16	--	30			
Picea abies	56°33'N	13°13'E	3.7	22	A	0-5		20	--	90		2	DAGMAR, 2003
Picea abies	50°12'N	11°53'E	3.5	26	A	0-5		15	--	35			
hoop pine	48°12'N	07°11'E	6		A	0-10		12	--	13.4		2	BLUMFIELD, 2004
Red pruce	26°31'N	152°3'E	4.1	19.4	A	0-10		8.4	--	37	1.5	2	SULTANA, 2004
American beech	44°52'N	68°06'E	4.4	20.2	A	0-10		25.2	--	66	3.3		
Norway spruce	56°29'N	8°24'E		33	B,C	0-5		20	--	13		4	GUNDERSEN, 1998
	56°29'N	8°24'E		33	B,C	0-5	NH_4NO_3	20	35	24			
Norway spruce	35°23'S	148°5'E		30.8	A	0-10		10	--	12.1		3	HOSSAIN, 1995
	35°23'S	148°5'E		30.8	A	0-10	Urea	10	100	24.1			
Brich-pine	62°46'N	30°58'E	4.7		C			27	--	87	52		
Brich-pine	62°46'N	30°58'E	4.8		C		KNO_3	27	100	107	60	1	REGINA, 1997
Brich-pine	62°46'N	30°58'E	4.5		C		NH_4Cl	27	100	129	63		
Brich-pine	62°46'N	30°58'E	4.8		C		Urea	27	100	91	74		
Picea abies	58°4'N	12°01'E			B		NH_4NO_3	12	35	27	-4		
P. abies	56°29'N	8°24'E			B		NH_4NO_3	18	35	13	0.01	6	GUNDERSEN, 1998
P.sitchenises	53°1'N	4°E			B		NH_4NO_3	17	35	68	7		
Scots pine	59°54'N	8°34'E	3.7		C	0-14		10	--	-7.7			
Scots pine	59°54'N	8°34'E	3.7		C	0-14	NH_4NO_3	10	30	-17.2		2	VESTFARDEN, 2003
Scots pine	59°54'N	8°34'E	3.7		C	0-14	NH_4NO_3	10	90	89.8			
masson	104°4'N	29°38'E	3.5	17.9	A	0-15		38	--	62.6	36.4	1	CHEN, 2007
pine	112°3'N	27°55'E	3.9	15.2	A	0-15		44	--	52.4	33.6		
pine	42°3'N	72°1'W	3.2	23.7	A			8	--	60-100			
pine	42°3'N	72°1'W	3.2	23.7	A		NH_4NO_3	8	50	51-155		9	MAGILL, 2000
pine	42°3'N	72°1'W	3.2	23.7	A		NH_4NO_3	8	150	75-190			
Sitka spruce	53°12'N	4°W		31	C			28	--	67.7	7	2.5	EMMETT, 1995
white spruce	53°12'N	4°W		31	C		NH_4NO_3	28	75	89.6	22.3		
white spruce	64°45'N	148°2'W	7.6	17.3	A	0-20		19	--	29.7		2	RICHARD, 2005
white spruce	64°45'N	148°2'W			A	0-20	$NaNO_3$	19	100	48.4			
deciduous	45°22'N	79°07'W	4.1	19	C	0-10		9.6	--	53.7	27.5	1	
Conifer-Mixed	45°22'N	79°07'W	4.2	18	C	0-10		9.6	--	46.5	1.4		KEVIN, 1999
Peatland	45°22'N	79°07'W	3.7	27	C	0-10		9.6	--	15.4	0.5		
Chinese pine	40°00'N	115°3'E			B	0-15		32.5	--	22.7		1	SU B, 2001
					B	0-15			--	55.5			
Norway spruce	51°31'N	934E		26	A	0-5		33	--	34	16	11	MARIFE, 2004
Red spruce	43°26'N	72°27'W			C	0-5		16	--	10		14	
Red spruce	43°26'N	72°27'W			C	0-5	NH_4NO_3	16	15.7	18-50			STEVEN, 2005
Red spruce	43°26'N	72°27'W			C	0-5	NH_4NO_3	16	31.4	8-50			

[a] A for Buried bag method，B for Close-top tube incubation technique，C for Resin-core technique

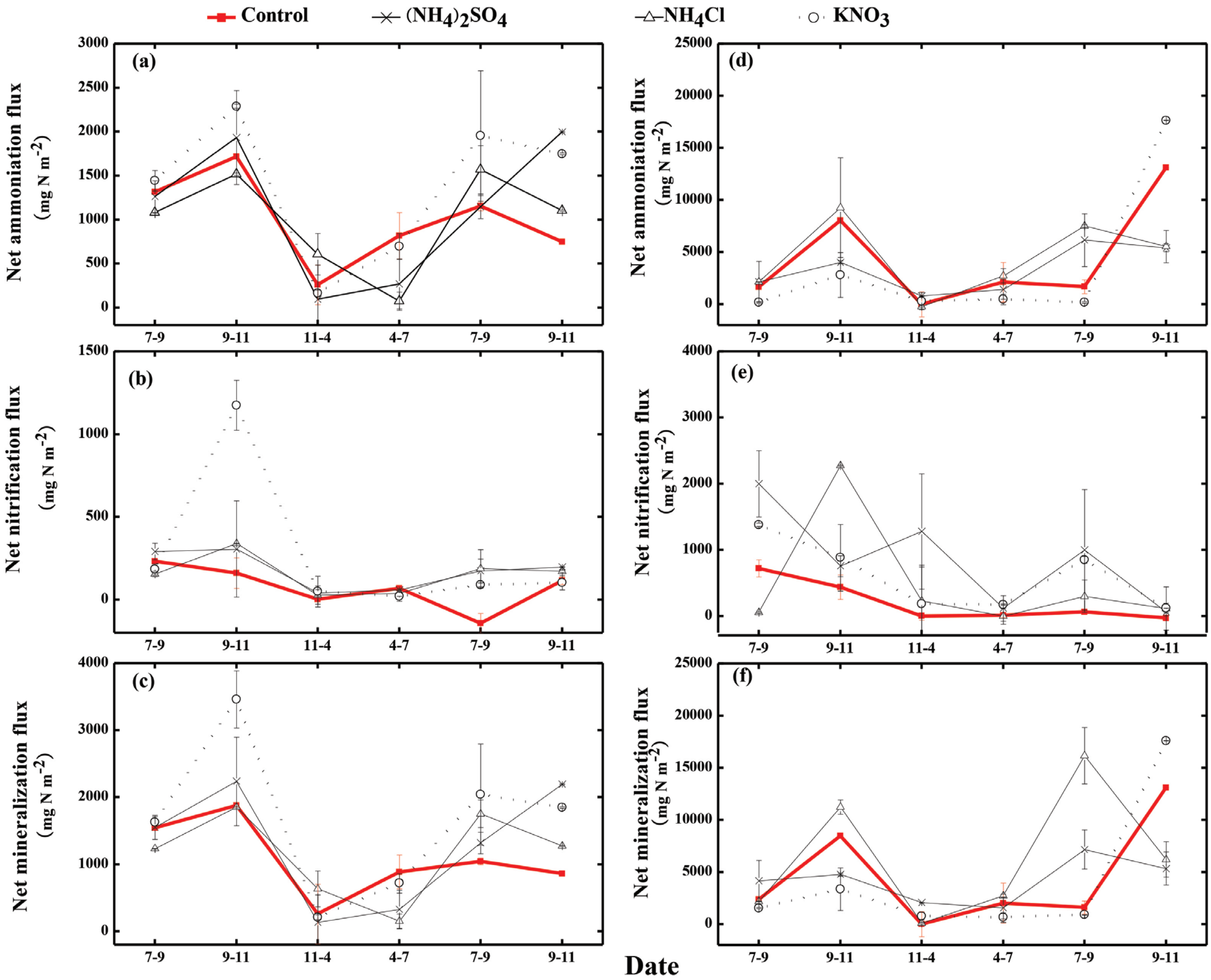

Figure 5. Th effect of low nitrogen input on soil net ammonification, net nitrification, and net mineralization in different years. a-c: 0-7cm; d-f: 0-15cm; Error bar is standard error for four repeated measurements.

high dose was much more obvious and the contribution rate of exogenous nitrogen input to the net mineralization flux of soil nitrogen was about 64%. VESTGARDEN et al. (2003) reported that 34% of the net mineralization flux of Scots pine (*Pinus sylvestris*) forest soil nitrogen in Northern Norway is attributed to exogenous nitrogen application.

Another observed result by MCNULTY et al. (2005) showed that the average contribution rate of nitrogen deposition increased the net mineralization flux of forest soil nitrogen for about 21% over a 12 year observation period. They also found the contribution rates of nitrogen deposition to the net mineralization flux of the forest soil nitrogen in different areas were significantly different. This may be closely related to forest type, climatic factors (such as annual precipitation and average annual temperature), and soil attributes.

3.3. Prediction of the effect of simulated nitrogen deposition on the annual net mineralization flux of forest soil nitrogen in different areas

Until now, both Chinese and international research on the response of soil nitrogen transformation in forest ecosystems to atmospheric nitrogen deposition was mainly conducted in sample plots and communities which were relatively small in scale. The focus of this research was mainly on the investigation of the mechanism of net mineralization flux of soil nitrogen. Investigation of the influence of nitrogen input and its synergistic factors on the net mineralization flux of forest soil nitrogen from the perspective of the regional scale was not addressed properly in the literature. In reality, the net mineralization fluxes of soil nitrogen show great differences in different forest ecosystems due to different vegetation, soil matrix, and climatic factors. Hence, on a global scale, for a deep understanding of global forest soil nitrogen transformation patterns and for a response to global warming, it is extremely essential to establish the law leading to zonal distribution of net mineralization of forest soil nitrogen as well as its influencing factors.

In the section, the results of the current research on the influence of nitrogen deposition increase on main soil carbon and nitrogen processes in regional forest ecosystems is summarized. The correlation between environmental factors such as climatic and biotic factors is discussed in Table 1. The results show that the annual net mineralization flux of forest soil nitrogen significantly increases linearly with the increase in atmospheric nitrogen deposition. In addition, the contribution rate of nitrogen deposition to the annual net mineralization flux of the forest soil nitrogen is about 48% (Figure 7.). According to CHEN & JAN (2007), in East China, when the nitrogen deposition was 25-49 N kg ha^{-1} yr^{-1}, the net mineralization flux of subtropical forest soil

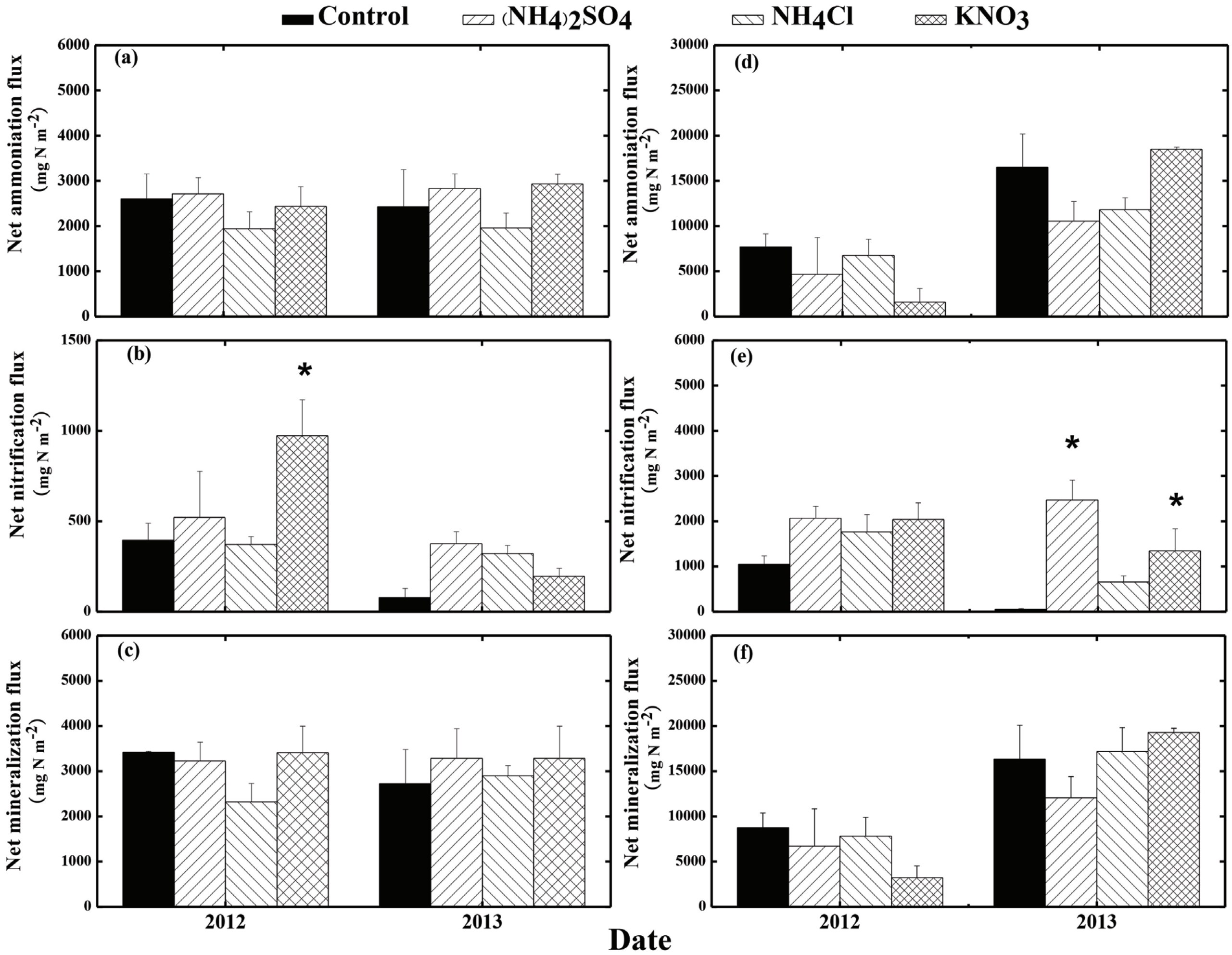

Figure 6. The effect of low nitrogen input on soil net annual nitrogen mineralization in different years. a-c: 0-7cm; d-f: 0-15cm; Error bar is standard error for four repeated measurements. * is significant level with contrast.

nitrogen was 52-62 N kg ha^{-1} yr^{-1}, and the contribution rate of nitrogen deposition to the net mineralization flux of soil nitrogen was 34%. PÉREZ et al. (1998) studied the annual net mineralization flux of temperate old-growth forest soil nitrogen in North America. They reported that the net mineralization flux of Hinoki cypress (Chamaecyparis obtuse) forest soil nitrogen was 20-23 N kg ha^{-1} yr^{-1}, and that of beech forest soil nitrogen was 31-37 N kg ha^{-1} yr^{-1}. A long period of atmospheric nitrogen deposition increase would reduce the carbon-to-nitrogen (C/N) ratio of the forest soil in the Northern Hemisphere and then the promoted soil nitrogen mineralization flux. Based on GUNDERSEN (1998), when atmospheric nitrogen deposition was 13-59 N kg ha^{-1} yr^{l}, the net mineralization flux of European coniferous forest soil nitrogen increased with the increase in nitrogen deposition. The contribution rate of nitrogen deposition to the net mineralization flux of soil nitrogen was 38%.

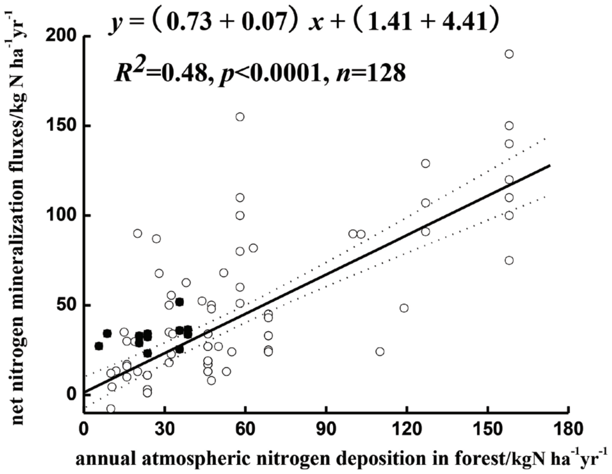

Figure 7. The relationship between net nitrogen mineralization fluxes with annual atmospheric nitrogen deposition in forest ecosystem. Solid circles are data points for the current observations, open circles are data points for previous in situ observational data.

4. CONCLUSION

Net ammonification accounts for about 76-89% of the net mineralization; while it decreases to 64-83% in KNO_3 treatments. The net N mineralization rate increased with nitrogen input, especially in $NH4_+^-$-N treatments ($p<0.05$). However, this promoting role decreased over time in longer experiments. At the highest $(NH_4)2SO_4$ addition, the net ammonification and net mineralization rate increased more clearly in the humus (0-7cm) than in the uppermost mineral layer (0-15 cm). A compilation of previous studies conducted on soil net mineralization from forests under different environmental conditions was evaluated for the effects of atmospheric N deposition and environmental factors, annual precipitation, and annual temperature on annual fluxes of net nitrogen mineralization in forest soils in the global scale. The results showed that increased atmospheric N deposition significantly enhanced the soil net nitrogen mineralization rate. The variations in atmospheric N deposition account for 48% of the variation in rates of soil net nitrogen mineralization across the forests.

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