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Nitrogen sink in a small forested watershed of subtropical China

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Abstract

Global nitrogen (N) emission and deposition have been increased rapidly due to massive mobilization of N which may have long-reaching impacts on ecosystems. Many agricultural and forest ecosystems have been identified as secondary N sources. In the present study, the input-output budget of inorganic N in a small forested watershed of subtropical China was investigated. Inorganic N wet deposition and discharge by stream water were monitored from March, 2007 to February, 2009. The concentrations and fluxes of inorganic N in wet precipitation and stream water and net retention of N were calculated. Global N input by dry deposition and biological fixation and N output by denitrification for forested watersheds elsewhere were reported as references to evaluate whether the studied forested watershed is a source or a sink for N. The results show that the inorganic N output by the stream water is mainly caused by NO_3^--N even though the input is dominated by NH_4^+-N. The mean flux of inorganic N input by wet precipitation and output by stream water is 1.672 and 0.537 g N/(m^2·yr), respectively, which indicates that most of inorganic N input is retained in the forested watershed. Net retention of inorganic N reaches 1.135 g N/(m^2·yr) considering wet precipitation as the main input and stream water as the main output. If N input by dry deposition and biological fixation and output by denitrification are taken into account, this subtropical forested watershed currently acts as a considerable sink for N, with a net sink ranging from 1.309 to 1.913 g N/(m^2·yr) which may enhance carbon sequestration of the terrestrial ecosystem.

Key words: forested watershed; nitrogen deposition; nitrogen sink; subtropical China

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Introduction

How does the terrestrial ecosystem respond to the ever-changing pattern of the global biogeochemical cycling of nitrogen (N) is a worldwide concern. During the past decades, emissions of ammonia (NH_3) and nitrogen oxides (NO_x) and their reaction products (NH_4^+, HNO_3 and NO_3^-) have increased rapidly due to massive mobilization of N by increased combustion of fossil fuels and expansion of industrial activity and agriculture (Vitousek et al., 1997). The anthropogenic N additions affect climate, the chemistry of the atmosphere, and the composition and function of terrestrial and aquatic ecosystems (Boring et al., 1988; Duce et al., 2008; Fenn et al., 2009). Given expected trends in population, demand for food, agricultural intensification and energy use, reactive N (Nr) creation is fated to increase even further in the future (Galloway et al., 2008), which will subsequently result in widespread increase of atmospheric N deposition.

The responses of forest ecosystems to increased atmospheric N deposition have been well documented in the temperate and boreal zones of Europe and North America. For example, increased N deposition may lead to N saturation (Aber et al., 1989) which has been defined as a condition that occurs when the availability of inorganic N is in excess of biological demand. If forest ecosystems were to reach this condition, several adverse effects would appear including nutrient imbalance in foliage, aggravation in soil acidification and leaching of nitrate into groundwater (Grennfelt and Hultberg, 1986; Dise and Wright, 1995). Yet, forest ecosystems have been shown to vary in their responses to increased N deposition. For instance, it is recognized that N deposition may enhance tree growth when it is not excessive for the ecosystem demand (Bytnerowicz and Fenn, 1996). The timing and magnitude of responses depend largely on the initial N status of the forest ecosystems and how close they are to N saturation (Gundersen et al., 1998; Aber et al., 2003). At the global scale, factors such as temperature and rainfall are considered to affect forest N cycling and subsequently the response to N deposition. At the regional scale, the heterogeneous nature of forest ecosystems, such as soil N pool size, species composition, stand age, and land-use

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history are major factors controlling the response pattern, as they influence the balance between N availability and biological demand.

The highly-weathered tropical and subtropical ecosystems with widespread existence of phosphorus-and-cation-deficient soils differ markedly from the temperate and boreal ecosystems where relative young soils are commonly distributed (Matson et al., 1999). Consequently, the responses of these systems to N deposition could be very different from those of temperate ecosystems. Yet, data on N status of such ecosystems and their responses remain notably rare (Galloway et al., 2008).

Elevated N deposition has been reported in tropical and subtropical China since 1980s (Li, 1984), and the current deposition of N has reached the same order of the magnitude as in Europe and North America (Chen and Mulder, 2007a). The continued increase of N deposition in tropical and subtropical China raises questions concerning consequences of anthropogenic N input for ecosystems in these regions. N input-output budgets provide a useful tool for evaluating N status of ecosystems and their responses to increased N deposition. Although numerous N input-output budgets have been developed for forested watersheds in the northeastern United States and some parts of Europe, such work in tropical and subtropical China where variable charge soils are distributed is limited (Chen and Mulder, 2007a, 2007b; Du et al., 2008; Fang et al., 2009). Furthermore, previous studies simply exclude N fixation and denitrification in N budgets and rarely evaluate whether the forest ecosystems act as sources or sinks for N at small watershed scale, when all pathways of N input and output are considered. In the present study, the input and output dynamics of inorganic N in a small forested watershed located in subtropical China were investigated and quantified. The objectives of this article are to estimate the input and output balance by quantifying concentrations and fluxes of inorganic N in wet precipitation and stream water, and to evaluate whether the studied forested watershed acts as a source or a sink for N.

1 Materials and methods

1.1 Study area

The studied forested watershed in Fengxingzhuang (FXZ) watershed with an area of 3.59 km^2 is located in the southern Anhui Province in subtropical China (30°33′N, 118°2′E). It lies on the southern part of the lower reaches of the Yangtze River (Fig. 1). This region belongs to a subtropical monsoon climate zone that is characterized by hot wet summer and cold dry winter. The mean annual temperature is 16.5°C and the mean annual precipitation is 1585 mm.

A survey conducted in the FXZ forested watershed in 2007 shows that the coniferous forest is about 30 years old. As for arbor species, pine (*Pinus tabulaeformis*) approximately accounts for 80%, fir (*Cunninghamia lanceolata*) 10%, and chestnut (*Castanea mollissima*) 6% of the total stand. The major shrubs are camellia (*Camelliasinensis*), mulberry (*Morus alba*) and azalea (*Rhododendron simsii*). Some bamboos (*Phyllostachys pubescens*) also grow here.

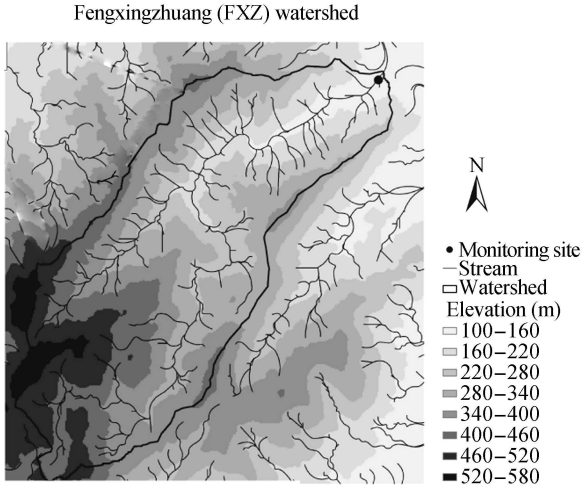

Fig. 1 Location of the sampling site and digital elevation model (DEM) of the Fengxingzhuang (FXZ) forested watershed.

The topography of the FXZ forested watershed is rather heterogeneous with slopes varying from 15° to 65°. It has an elevation range from 100 to 575 m (Fig. 1). The soils are typically thin and primarily overlie granitic parent material (Gu et al., 2003). The average soil depth is about 50 cm and consists of an upper organic horizon and a deeper mineral soil layer. The surface soil (0–10 cm), with a C/N ratio of 25, has an average pH value of 5.09, and the bulk density is 1.26 g/cm^3. The parent rock was formed in the Late Yenshan movement of the Late Cretaceous Period (Gu et al., 2003). The major soil types are Udic Argosols and Cambosols according to Chinese Soil Taxonomy (CST) (Gong et al., 2007); or Lixisols and Cambisols by World Reference Base for Soil Resources (WRB) (IUSS Working Group WRB, 2006).

1.2 Sampling and chemical analysis

The rain and stream water were monitored from March, 2007 to February, 2009 in the FXZ forested watershed. The weather station (Watchdog Model 900ET Weather Station, Spectrum Technologies Inc., USA) and an automated wet/dry deposition collector (PSC-III, Qingdao PR Instrument Co., China) were installed at the top of a small house of 5 m height in the watershed. Rainfall, solar radiation, wind speed, wind direction, relative humidity and air temperature were recorded in a data logger every 15 min and the data were retrieved weekly. Wet precipitation was collected continuously and sampled at weekly intervals. For runoff determination and collection, a normative flume was built near the outlet of the watershed. A pool was built in front of the flume for holding sediment and was cleaned up immediately after rainfall. An automatic runoff collector (ISCO6712, North America Instrument Consultants Co., USA) with a water level sensor was installed indoors near the flume site. The flow volume was automatically transformed by the instrument software based on the detected flow depth and the normative flume

dimensions. Water samples (1000 mL each) were collected automatically by the instrument whenever the rise or fall of flow depth reached 2 cm in 30 min. The instrument recorded sampling times simultaneously. The stream water samples were also collected weekly.

Water samples were analyzed as soon as they were transported back to the laboratory. The pH value and the electric conductivity were determined in unfiltered solutions at 25°C by pH meter (PHS-3C, Shanghai REX Instrument Factory, China) and conductivity meter (DDS-307, Shanghai REX Instrument Factory, China), respectively. Then the samples were filtrated (0.45 μm membrane filter) into plastic bottles and stored at 4°C for chemical analysis. Concentration of NH_4^+-N was analyzed by the Indophenol Blue method followed by colorimetry (APHA, 1998) and NO_3^--N was analyzed by ion chromatography according to EMEP manual (1996). The quality of chemical analysis was checked by including method blanks, repeated measurements of internal and certified reference samples.

1.3 Calculations and statistics

The fluxes of inorganic N in wet precipitation and stream water were calculated daily or weekly for the samples by multiplying the measured amount of rainfall and stream flow with their concentrations that then were summed to get monthly, seasonal and annual fluxes.

Relationships between concentrations and fluxes of inorganic N in wet precipitation and stream water were analyzed with linear regression analysis. Simple Pearson correlation coefficients were calculated between concentrations and fluxes of inorganic N both in wet precipitation and stream water. The Statistical Program for Social Sciences program (SPSS 13.0 for Windows) was used to carry out the analysis.

2 Results and discussion

2.1 Water fluxes and pH values

The annual precipitation in the FXZ forested watershed is 1534 mm/yr. The summer rainfall accounts for 48% of the annual rainfall varying from 689 to 760 mm in the two observed years (Fig. 2). This seasonal pattern of wet precipitation is due to the prevailing monsoon climate, by which warm winds from the ocean cause copious amounts of rainfall during the southeast or summer monsoon, while dry continental air masses from Siberia result in cold and dry winter during the northeast or winter monsoon. The annual stream water flux in this studied area is 765 mm/yr with the maximum flux of 321 to 440 mm in summer (Fig. 2). The annual stream water flux accounts for about 50% of the annual rainfall amount which indicates that 50% of precipitation is distributed to canopy interception, evaporation, and soil water retention. Seasonal variation of water flux in stream water closely followed by the wet precipitation (Fig. 2) both with the most of flux occurred during the rainy season (spring and summer). The correlation of monthly flux between wet precipitation and stream water was checked using Pearson correlation with a coefficient of 0.92 (n = 24) which is significant at the 0.01 level (two-tailed).

The monthly mean pH value varies from 3.78 to 5.06 in wet precipitation with the average value of 4.43 (Fig. 2) which indicates that rain water is acidic. The occurrence of acid precipitation in the FXZ forested watershed is more than 100 km away from any large urban-industrial area emphasizing the severe impact of atmosphere pollution on natural ecosystem. In contrast, the monthly mean pH value in stream water is much higher than that in wet precipitation in the studied forested watershed varying from 6.73 to 7.24 with the average value of 6.98 (Fig. 2). This implies that a large amount of free hydrogen ion

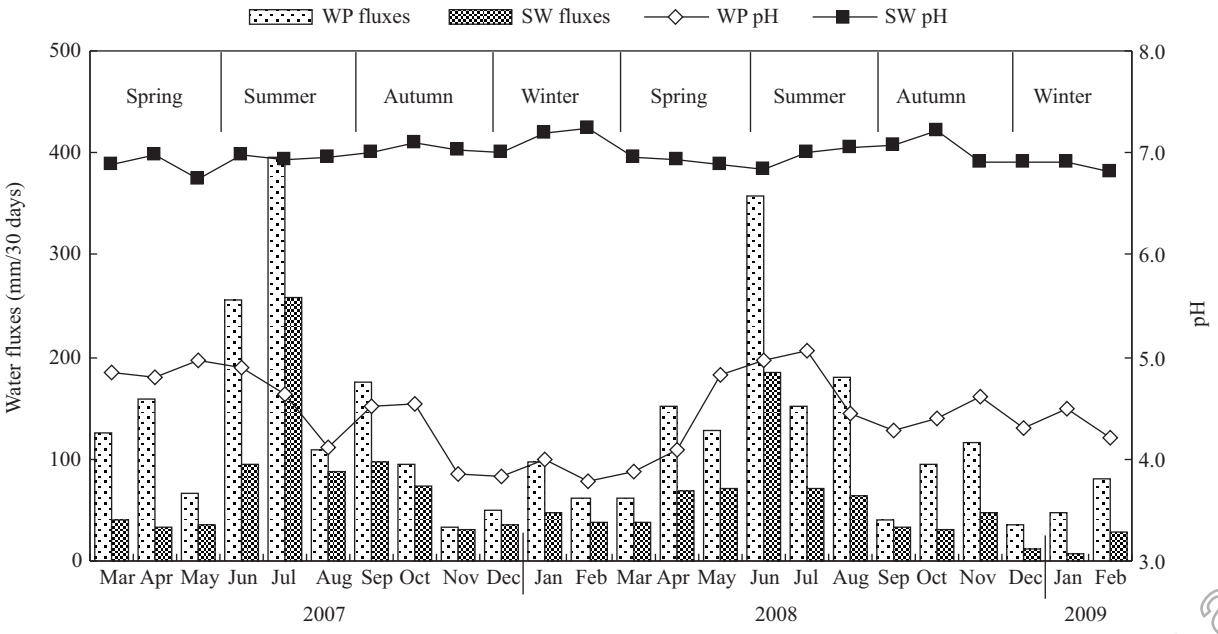

Fig. 2 Water fluxes and monthly mean pH values in the wet precipitation (WP) and stream water (SW) in the two observed years.

entering the system is retained or consumed in the soil which confirms the lagged response between acid inputs and outputs. The pH of wet precipitation correlates with rainfall amount, with a correlation coefficient of 0.53 ($p < 0.01$, $n = 24$) while there is no evident correlation between pH of stream water and stream water flux. There is a negative correlation between the pH of wet precipitation and that of stream water with a correlation coefficient of –0.46 ($p < 0.05$, $n = 24$). This may be due to that wet precipitation with stronger acidity should lead to a larger quantity of base cations leaching from the soil into stream water and thus cause a higher pH value of stream water.

2.2 Concentrations of NH_4^+-N and NO_3^--N

Mean monthly concentration of NH_4^+-N in wet precipitation ranges from 0.294 to 1.053 mg N/L with the mean value of 0.613 mg N/L. The mean monthly concentration of NO_3^--N in wet precipitation ranges from 0.219 to 1.011 mg N/L with the average value of 0.536 mg N/L (Fig. 3). Both NH_4^+-N and NO_3^--N concentrations in wet precipitation in the FXZ forested watershed are much higher than an earlier report data for remote sites (Galloway et al., 1982), but lower than the values reported recently for urban areas in south China (Tu et al., 2005) and western USA (Lehmann et al., 2005). NH_4^+-N and NO_3^--N concentrations in wet precipitation show a similar seasonal pattern during the two years of the study period (Fig. 3) as confirmed by their highly significant linear correlation ($r = 0.723$, $p < 0.01$, $n = 24$). Their concentrations were higher in the rainy season (spring and summer) than in the dry season (autumn and winter). Both NH_4^+-N and NO_3^--N concentrations reached the lowest level in winter in the two observed years. The output concentrations of NH_4^+-N and NO_3^--N in stream water change dramatically compared with those in wet precipitation. The mean monthly concentration of NH_4^+-N in stream water varies from 0.021 to 0.289 mg N/L with the mean value of 0.128 mg N/L. The mean monthly concentration of NO_3^--N in stream water varies from 0.324 to 1.445 mg N/L with the mean value of 0.631 mg N/L (Fig. 3). The concentration of NO_3^--N in stream water tends to decrease during the growing season (from May to October) as a result of biological uptake in the two observed years (Fig. 3). Ohrui and Mitchell (1997) reported that there was no evident seasonal variation in NO_3^--N concentration of stream water due to nitrogen saturation. However, at our studied area, NO_3^--N concentration in stream water changes with season indicating that nitrogen saturation does not appear in the FXZ forested watershed.

The concentration of NO_3^--N in wet precipitation correlates with rainfall amount with a correlation coefficient of –0.469 ($p < 0.05$, $n = 22$), showing that rainfall has a dilution effect on NO_3^--N concentration. The pH of wet precipitation has also a negative correlation with the concentration of NO_3^--N in wet precipitation ($r = –0.590$, $p < 0.01$, $n = 24$), which indicates that NO_3^--N concentration has an important effect on the acidity of wet precipitation. However, neither the pH of wet precipitation nor the amount of rainfall correlates with the concentration of NH_4^+-N in wet precipitation in this study. There is no correlation between the pH of wet precipitation and the concentration of inorganic nitrogen in stream water, which suggests that the acidity of wet precipitation in this studied area is not the immediate factor of inorganic nitrogen output. In addition, both the fluxes of wet precipitation and stream water are not significantly correlated with the concentration of inorganic nitrogen in stream water. The concentration of NO_3^--N in stream water is significantly correlated with the NO_3^--N concentration in wet precipitation ($r = 0.426$, $p < 0.05$, $n = 24$). However, there is no correlation between the concentration of NH_4^+-N in stream water and wet precipitation, which is due to the different biogeochemical cycling mechanisms of ammonium and nitrate.

2.3 Inorganic nitrogen fluxes

Seasonal fluxes of NH_4^+-N, NO_3^--N and total inorganic nitrogen (TIN) in wet precipitation and stream water in the FXZ forested watershed are shown in Table 1. Fluxes of NH_4^+-N, NO_3^--N in wet precipitation vary from 0.109 to 0.467 g N/(m^2·90 days) and from 0.092 to 0.323 g N/(m^2·90 days), respectively, both with the maximum in summer in the two observed years. The flux of TIN in wet precipitation also varies from 0.214 to 0.745 g N/(m^2·90 days), also with the maximum in summer, accounting for more than 40% of the total annual flux. The mean annual

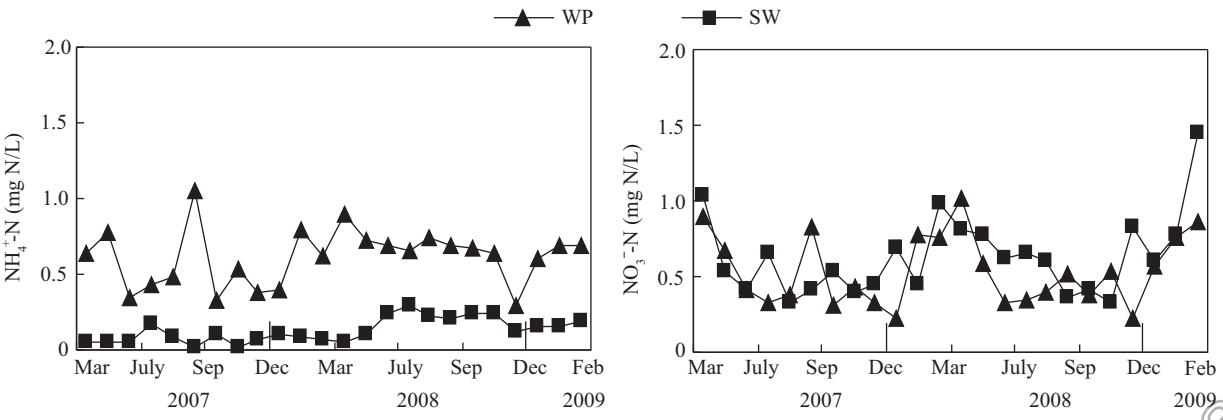

Fig. 3 Temporal variation in monthly concentrations of NH_4^+-N and NO_3^--N in wet precipitation (WP) and stream water (SW) in the FXZ forested watershed from March, 2007 to February, 2009.

Table 1 Seasonal fluxes of NH_4^+-N, NO_3^--N and total inorganic nitrogen (TIN) in WP and SW in the FXZ forested watershed

Year	Season	WP (g N/(m^2·90 days))			SW (g N/(m^2·90 days))		
		NH_4^+-N	NO_3^--N	TIN	NH_4^+-N	NO_3^--N	TIN
2007	Spring	0.224 (48)	0.245 (52)	0.470	0.010 (11)	0.075 (93)	0.085
	Summer	0.415 (56)	0.323 (44)	0.738	0.040 (18)	0.182 (82)	0.222
	Autumn	0.120 (52)	0.108 (48)	0.228	0.013 (12)	0.096 (88)	0.109
	Winter	0.134 (50)	0.133 (50)	0.267	0.006 (7)	0.083 (89)	0.089
	Total	0.894 (53)	0.808 (47)	1.703	0.069 (14)	0.436 (86)	0.505
2008	Spring	0.252 (57)	0.194 (43)	0.447	0.026 (17)	0.127 (83)	0.153
	Summer	0.467 (63)	0.279 (37)	0.745	0.082 (30)	0.189 (70)	0.271
	Autumn	0.122 (57)	0.092 (43)	0.214	0.021 (25)	0.064 (75)	0.085
	Winter	0.109 (47)	0.125 (53)	0.234	0.008 (13)	0.053 (87)	0.061
	Total	0.950 (58)	0.690 (42)	1.640	0.137 (24)	0.433 (76)	0.570

Values in parentheses indicate respective percentage of NH_4^+-N and NO_3^--N in TIN. WP: wet precipitation; SW: stream water.

input of wet-only TIN in this studied area is 1.672 g N/(m^2·yr), which is comparable to the values reported from some other parts of southern China (Chen and Mulder, 2007a), but higher than those observed in most forests in North America (Campbell et al., 2004) and Japan (Ohte et al., 2001). A small portion of nitrogen, relative to the high deposition, flows into stream. Fluxes of NH_4^+-N and NO_3^--N in stream water vary from 0.006 to 0.082 g N/(m^2·90 days) and from 0.053 to 0.189 g N/(m^2·90 days), respectively, with the highest value in summer and the lowest in winter. The output of TIN in stream water varies from 0.061 to 0.271 g N/(m^2·90 days), with the mean annual value of 0.537 g N/(m^2·yr), which is higher than 0.090 g N/(m^2·yr) in an undisturbed rainforest of southern Chile (Oyarzu'n et al., 2004), but greatly lower than 8.918 g N/(m^2·yr) in Speuld and 6.902 g N/(m^2·yr) in Ysselsteyn, Europe with nitrogen saturation (Bredemeier et al., 1998). This implies that nitrogen is unsaturated in the FXZ forested watershed. The output of TIN in stream water is tightly coupled with stream discharge (r = 0.861, $p < 0.01$, n = 24), which indicates that temporal variation of N output is strongly controlled by hydrological factors, but not by biological factors (e.g., uptake by vegetation).

NH_4^+-N fluxes account for 47% to 63% of TIN in wet precipitation, with the mean value of 56%. However, in stream water NH_4^+-N fluxes only account for 7% to 30% of TIN, with the mean value of 17% (Table 1). Consistent with this result, most studies from other parts of China (Chen and Mulder, 2007a; Du et al., 2008) reported that the inorganic nitrogen input by wet precipitation is mainly in NH_4^+-N while the output by stream water is mainly in NO_3^--N. Possible transformations causing low NH_4^+-N output include adsorption on soil surface, uptaken by vegetation, microbial immobilization and nitrification (Campbell et al., 2004).

2.4 Inorganic nitrogen budgets

Considering wet precipitation as input and stream water as output in the FXZ forested watershed, mean monthly budgets of NH_4^+-N, NO_3^--N and TIN are shown in Fig. 4. The net retentions of NH_4^+-N and NO_3^--N are in the range of 0.010–0.179 and –0.014~0.088 g N/(m^2·30 days),

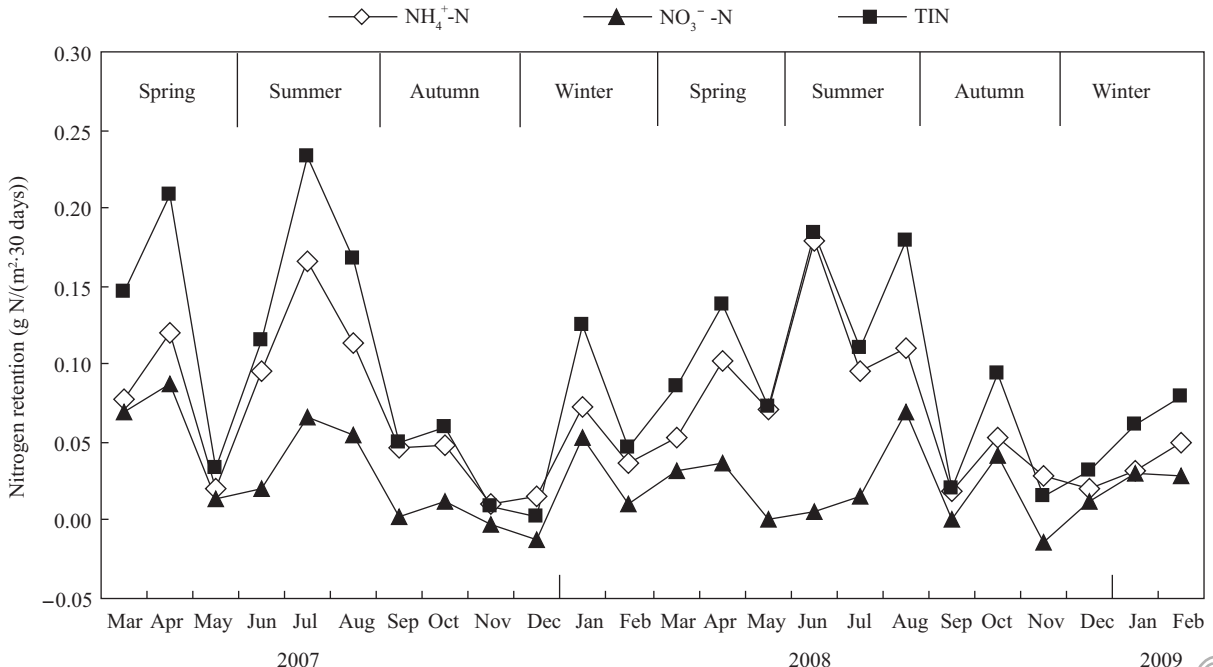

Fig. 4 Mean monthly budgets of NH_4^+-N, NO_3^--N and total inorganic nitrogen (TIN) considering wet precipitation as input and stream water as output for the FXZ forested watershed.

with the mean value of 0.068 and 0.026 g N/(m^2·30 days), respectively. The mean monthly net retention of NH_4^+-N is much higher than NO_3^--N (Fig. 4), which is due to that ammonium adsorption on the soil surface is strong while nitrate adsorption is negligible, and also ammonium is more easily absorbed by the canopy relative to nitrate (Presscott, 2002). In addition, ammonium nitrification may cause higher retention of NH_4^+-N relative to NO_3^--N as well. Several studies in acid forest soils with ample nitrogen supply indicate that ammonium can be nitrified even at low pH values (Likens et al., 1969; Van Breemen et al., 1984), which will subsequently drive the production and loss of nitrate. Net retentions of NH_4^+-N and NO_3^--N in the FXZ forested watershed show a similar seasonal pattern in the two observed years, as confirmed by their highly significant linear correlation ($r = 0.633$, $p < 0.01$, $n = 24$). The net retention of TIN ranges from 0.003 to 0.232 g N/(m^2·30 days), with the mean value of 0.095 g N/(m^2·30 days) in the two observed years. The retentions of NH_4^+-N, NO_3^--N and TIN in the FXZ forested watershed are higher in growing season (spring and summer) than dormant season (autumn and winter) (Fig. 4), mainly because of the vegetation that assimilate much more NH_4^+-N and NO_3^--N in the growing season while some tree species defoliate in the dormant season. The export of NO_3^--N in stream water even exceeds NO_3^--N input in wet deposition in November or December in the two observed years, indicating that nitrogen saturation may occur in the dormant season.

The annual average retention of TIN in the FXZ forested watershed is 1.135 g N/(m^2·yr), which is comparable to the values reported for some forests in Europe (Bredemeier et al., 1998), but higher than most forests in Japan (Ohte et al., 2001) and United States (Campbell et al., 2004). Although relative high level of nitrogen retention in the FXZ forested watershed, the value is much lower than 2.916 g N/(m^2·yr) as reported for Shaoshan forest in Central-South China (Du et al., 2008). Differences in nitrogen retention observed by different studies are mainly due to three reasons: (1) nitrogen input varies spatially around the world; (2) the ecosystem characteristics (e.g., hydrology, vegetation type and land-use history) affect nitrogen loss (Campbell et al., 2004); and (3) the capacity of forest to retain nitrogen depends largely on nitrogen status of the ecosystem (Gundersen et al., 1998).

2.5 Is the FXZ forested watershed a source or a sink for nitrogen?

Since the gradient of the FXZ forested watershed is cragged and the parent rock is solid granite, which can prevent soil water from infiltrating into groundwater, nitrogen loss by groundwater is assumed to be negligible. Thus, in this studied forested watershed nitrogen input pathways include biological fixation, wet and dry deposition, while nitrogen output pathways include nitrogen denitrification and nitrogen loss in stream water. Because of the difficulties in estimating dry deposition and biological fixation of nitrogen, inorganic nitrogen input has relied upon wet deposition only. However, the total inorganic nitrogen input is expected to be even greater if dry deposition and biological fixation were included. On the other hand, nitrogen loss by denitrification is difficult to measure at small watershed scale due to the large spatial variability within watershed and problems associated with measurement methodology (Bowden et al., 1990), thus gaseous N flux was also not determined. Although nitrogen input by dry deposition and biological fixation as well as nitrogen loss by denitrification are not measured in this study, estimates from other reports are used as references to calculate whether the FXZ forested watershed acts as a source or a sink for nitrogen.

Previous studies showed that dry deposition generally constituted 25% to 30% of total atmospheric nitrogen deposition (Zeller et al., 2000; Burns, 2003). In contrast, biological nitrogen fixation was not evident in natural forest and of little importance in nitrogen input. Rosén and Lindberg (1980) investigated biological nitrogen fixation at five coniferous forested watersheds in Central Sweden and calculated an average value of 0.050 g N/(m^2·yr). Using these estimates as guide values, the total inorganic nitrogen input in the FXZ forested watershed may range from 2.296 to 2.460 g N/(m^2·yr). Denitrification rates reported for forest ecosystems were highly variable and have been reviewed by Barton et al. (1999) and Bowden (1986). The rates were generally higher in the deciduous hardwood and rainforest than those in the coniferous forest, and also higher in tropical regions compared with temperate regions (Bowden, 1986; Barton et al., 1999; Chen et al., 2000; Kiese and Butterbach-Bahl, 2002; Dong et al., 2003; Horvath et al., 2006). As for the coniferous forest, the denitrification rates ranged from < 0.01 to 0.45 g N/(m^2·yr) (Bowden, 1986; Barton et al., 1999; Chen et al., 2000; Dong et al., 2003; Horvath et al., 2006). Since the FXZ forest is mainly coniferous, nitrogen loss by denitrification is estimated in the range of < 0.01 to 0.45 g N/(m^2·yr). Thus total inorganic nitrogen output in the FXZ forested watershed can be estimated varying from < 0.547 to 0.987 g N/(m^2·yr). In this case, the FXZ forested watershed currently acts as a considerable sink for inorganic nitrogen, accounting for more than 60% of the total inorganic nitrogen input, varying from 1.309 to 1.913 g N/(m^2·yr), in contrast to the N saturation condition in many parts of Europe and North America. The fraction of inorganic nitrogen sink in this studied forested watershed consists of a combination of storage in biomass and soil (Van Breemen et al., 2002). This net storage of nitrogen can promote forest growth as the forest ecosystem has not grown mature yet and consequently enhance carbon sequestration (Grassi, 2007; De Vries et al., 2009). A recent study conducted in subtropical China has showed that even the old-growth forest (age > 400 years) can still accumulate carbon in soil (Zhou et al., 2006) in which nitrogen sink is possibly a contributing factor. Given the similarity of tropical and subtropical forests in south China, it is expected that the vast forest ecosystems in south China will probably remain as a huge sink for nitrogen and thus enhance enormous carbon sequestration but this necessitates further studies in more areas with comparable conditions.

3 Conclusions

The present results reveal that the atmospheric wet deposition of inorganic nitrogen in the studied forested watershed is relatively high. However, only a small amount of nitrogen is exported out of the watershed by surface drainage. Based on mass balance calculation, more than 60% of the input nitrogen has been retained in the forested watershed. We conclude that the FXZ forested watershed currently acts as a considerable sink for inorganic nitrogen, with a net sink ranging from 1.309 to 1.913 g N/(m^2·yr), which may enhance carbon sequestration of the terrestrial ecosystem. However, the relative size of nitrogen storage in forest biomass and soil remains uncertain, and how long the ecosystem will remain as a sink for nitrogen is also unknown. It is highly necessary to carry out such studies more extensively in subtropical China to get a clear result.

Acknowledgments

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