

Response of Nitrogen Leaching to Nitrogen Deposition in Disturbed and Mature Forests of Southern China*¹

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ABSTRACT

Current nitrogen (N) leaching losses and their responses to monthly N additions were investigated under a disturbed pine (*Pinus massoniana*) forest and a mature monsoon broadleaf forest in southern China. N leaching losses from both disturbed and mature forests were quite high (14.6 and 29.2 kg N ha⁻¹ year⁻¹, respectively), accounting for 57% and 80% of their corresponding atmospheric N inputs. N leaching losses were substantially increased following the first 1.5 years of N applications in both forests. The average increases induced by the addition of 50 and 100 kg N ha⁻¹ year⁻¹ were 36.5 and 24.9 kg N ha⁻¹ year⁻¹, respectively, in the mature forest, accounting for 73.0% and 24.9% of the annual amount of N added, and 14.2 and 16.8 kg N ha⁻¹ year⁻¹ in the disturbed forest, accounting for 28.4% and 16.8% of the added N. Great N leaching and a fast N leaching response to N additions in the mature forest might result from long-term N accumulation and high ambient N deposition load (greater than 30 kg N ha⁻¹ year⁻¹ over the past 15 years), whereas in the disturbed forest, it might result from the human disturbance and high ambient N deposition load. These results suggest that both disturbed and mature forests in the study region may be sensitive to increasing N deposition.

Key Words: atmospheric N deposition, N addition, N leaching loss, N saturation, subtropical forests

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INTRODUCTION

Nitrogen (N) is generally considered to be the growth-limiting nutrient for the terrestrial ecosystem (Aber *et al.*, 1989, 1998). However, human activities have more than doubled the inputs of N to terrestrial ecosystems globally (Matson *et al.*, 1999). A great number of studies on N deposition have been carried out in Europe and North America, where industrial development occur earliest (Matson *et al.*, 1999; Galloway *et al.*, 2003). Results have shown that in predominately N-limited temperate forests in these regions, the experimental and atmospheric N inputs had dramatically altered ecosystem processes and properties, including forest productivity, soil fertility, species composition, litter decomposition, and N loss from soils to groundwater and atmosphere (Aber *et al.*, 1993, 1998; Kahl *et al.*, 1993; Magill *et al.*, 1996, 2000, 2004; Emmett *et al.*, 1998; Fenn *et al.*, 1998; Gundersen, 1998; Gundersen *et al.*, 1998, 2006; Hall and Matson, 2003).

In tropical and subtropical regions, certain heavily populated areas show a high N deposition owing to the intensification of fossil fuel use and agricultural practices (Matson *et al.*, 1999; Galloway *et al.*, 2003). However, the impact of N deposition on natural forest ecosystems in these regions is not well understood yet. A range of evidence suggests that biological activity in many tropical forests, especially those with

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highly weathered soils, is not limited by N but rather by some other nutrient (*e.g.*, phosphorus, calcium) or by other resources (Vitousek, 1984; Jordan, 1985). Thus, it has been hypothesized by Matson *et al.* (1999) that moist tropical forest ecosystems are more sensitive to anthropogenic N load compared with temperate forest ecosystems. It has also been hypothesized that additions of N may have little effect on plant production and carbon storage but may substantially affect the rate and timing of N losses (Matson *et al.*, 1999). The N fertilization experiments in the tropical rain forests in the Hawaii Islands support this hypothesis. Their results showed that the nutrient status determined ecosystem responses to N additions (Hall and Matson, 2003). With respect to subtropical forests, currently there is limited scientific information on N cycling and its response to increasing anthropogenic N deposition (Bubb *et al.*, 1999; Xu *et al.*, 2001; Chen *et al.*, 2002; Xu *et al.*, 2002, 2003; Chen *et al.*, 2004). High atmospheric N deposition has already been observed in southern China, as in other parts of the world with rapid economic growth (Xu *et al.*, 2001; Chen *et al.*, 2004). We hypothesize that old growth, mature, or steady-state forests in this region may have been N-saturated due to long-term N accumulation and the warm and humid environments and thus exhibit a high N leaching loss and a fast response to N additions as suggested by Matson *et al.* (1999), whereas young, aggrading, and disturbed forests may still be N-limited and thus would exhibit a low N leaching loss and a slow response to N additions.

To investigate the risk and consequences of enhanced N deposition into subtropical forest ecosystems under warm and humid conditions, an N addition experiment was carried out in Dinghushan Biosphere Reserve of southern China in July 2003 (Fang *et al.*, 2006; Mo *et al.*, 2006; Xu *et al.*, 2006). This experiment provided a unique opportunity to test our hypothesis because a disturbed pine and a protected mature forest were included. The mature forest is a monsoon evergreen broadleaved forest, a regional climax type, and has been protected for more than 400 years by monks in the nearby temples. Long-term N accumulation may have already eliminated any N limitation in this forest (Mo *et al.*, 2006). In contrast, the disturbed forest originated from the 1930's clear-cut and the establishment of pine plantation. Moreover, the disturbed forest was under continuous human disturbances, generally the harvesting of understory and litter, during 1930 to 1998 (Mo *et al.*, 2003). As a result, both the productivity and N level in this site were low (Brown *et al.*, 1995; Mo *et al.*, 1995, 2003). The disturbed pine forest is, therefore, very likely to be an N-limited ecosystem. In this study, the data of N leaching losses and their responses to monthly N additions in the two forests were presented to test the hypothesis mentioned above.

MATERIALS AND METHODS

Study site

The Dinghushan Biosphere Reserve lies at the center of Guangdong Province (112° 10' E and 23° 10' N) in southern China. The climate in the area is humid and warm, with a mean annual precipitation of 1927 mm and a mean annual temperature of 21.0 °C (Huang and Fan, 1982). The topography is highly heterogeneous, with slopes ranging from 15° to 35°. The soil is lateritic red earth formed from sandstone (He *et al.*, 1982), with a thin layer of floor litter (0.5–3 cm).

The mature forest, at about 250–300 m above sea level (a.s.l.), occupies 20% of the reserve area, and the disturbed forest, at about 50–200 m a.s.l., occupies 20% (Mo *et al.*, 1995, 2003). Both forests are regionally representative types in South China (Mo *et al.*, 1995, 2003). The survey conducted in June 2003 (before the start of N addition experiments) showed that the major species in the mature forest were *Castanopsis chinensis*, *Machilus chinensis*, *Schima superba*, *Cryptocarya chinensis*, and *Syzygium rehderianum* in the canopy and sub-canopy layers, which represented up to 80% of the total basal area (Fang *et al.*, 2006). However, the disturbed forest was under continuous human disturbances during 1930 to 1998 so that the tree layer remained dominated by *Pinus massoniana* (Fang *et al.*, 2006). In the mature forest, the soil depth is between 30 and 70 cm, and in the disturbed forest, the soil depth is generally less than 50 cm (Fang *et al.*, 2003). For the 0–10 cm mineral soils, the disturbed forest

has significantly higher soil bulk density and soil pH than the mature forest but lower concentrations of total carbon, total nitrogen, and extractable NO_3^- -N (Table I).

TABLE I

General characteristics of the 0–10 cm mineral soil in pine and mature forests in Dinghushan Biosphere Reserve, southern China^{a)}

Forest	pH	Total C	Total N	C/N ratio	Extractable NH_4^+ -N	Extractable NO_3^- -N	Soil bulk density
		— g kg ⁻¹ —			— mg kg ⁻¹ —		g cm ⁻³
Disturbed	4.04±0.04 ^{b)}	28.3±3.1	1.1±0.1	25.1±1.1	3.7±0.2	2.7±0.3	1.16±0.05
Mature	3.83±0.02	45.5±2.3	1.9±0.1	22.1±1.3	2.1±0.1	12.5±1.3	0.98±0.06

^{a)}From Fang *et al.* (2006); ^{b)}Means ± standard errors ($n = 3$).

Experimental design

Three N treatments with three replications per treatment were established within each forest: control, low N (50 kg N ha⁻¹ year⁻¹), and medium N (100 kg N ha⁻¹ year⁻¹) (Fang *et al.*, 2006). An additional high N treatment (150 kg N ha⁻¹ year⁻¹) was installed in the mature forest, but this treatment was not discussed in this article. There were 12 plots and 9 plots for the mature forest and the disturbed forest, respectively. Each plot measured 10 m × 20 m, with about 10-m buffer strips around each plot. The nitrogen was added into the plots in the form of NH_4NO_3 solution monthly since July 2003. For each application, fertilizer NH_4NO_3 was weighed, mixed with 20 L of water, and applied to the plots using a backpack sprayer below the canopy. Two passes were made across each plot to ensure an even distribution of fertilizer. The control plots received 20 L water without N addition (Fang *et al.*, 2006).

Input and output of N

Bulk precipitation was sampled using three open glass funnels placed near a pluviometer in an open area in the reserve. Five collectors made of PVC, each with an intercept area of 0.8 m², were set up in each forest to sample throughfall. Stemflow was collected from two representative trees in each plot as described by Mo *et al.* (2002). One selected plot for each treatment had been delimited hydrologically by placing stable plastic materials and low cement barriers around them. The cement barriers on the downslope side of these plots were constructed to enable the sampling of the surface runoff. The other two plots for each treatment were assumed to have surface runoff flux of N equal to the measured flux under the same N treatment. Two porous ceramic cups were installed at 40 cm depth 3–4 months before the first sampling for all the plots except in one of the medium N plots in the mature stand because of its shallow soil condition. Soil solution samples at this depth represent leachates below the rooting zone and were collected by draining any existing water using a hand pump and applying a tension of 50 kPa. Approximately 24 h later, a sample was collected. Water samples were usually collected once every two weeks when possible, and the volumes of precipitation, stemflow, and throughfall were recorded for each sampling period. Stemflow and soil solution were composited within plots for each sample date.

Samples for NH_4^+ -N and NO_3^- -N analyses were filtered within 24–48 h of collection through a 0.45 μm filter and stored in plastic bottles at 4 °C until analysis. NH_4^+ -N concentration was determined using the indophenol blue method followed by colorimetry. NO_3^- -N concentration was determined after cadmium reduction to NO_2^- -N followed by sulfanilamide-nicotinamide adenine dinucleotide (NAD) reaction (Liu *et al.*, 1996). Output from each plot was measured as surface runoff plus soil solution below the rooting zone. Water balance has been well studied for both forest types in the Dinghushan Biosphere Reserve using the catchment method (Huang *et al.*, 1994; Mo *et al.*, 2002). Observation showed that the water fluxes of both surface runoff and soil solution below the rooting zone correlated well to that of precipitation. Thus, the soil was close to its water holding capacity throughout the wet season and water flow out of the rooting zone was largely determined by precipitation amount. We used the observed

relationships to estimate volumes of surface runoff and soil solution for each sampling period, then multiplied the estimated volumes by NH_4^+ -N and NO_3^- -N concentrations of the same period, and added the products to determine N fluxes for the study year.

Statistical analysis

One-way analysis of variance (ANOVA) was carried out to identify the differences in inputs of NH_4^+ -N and NO_3^- -N within throughfall and stemflow between the two forests. Two-way ANOVA was carried out to identify the effects of forest and N treatment on N leaching below the rooting zone. One-way ANOVA with Tukey's post hoc comparison was also used to determine the N treatment effect on N leaching for each forest. For the NH_4^+ -N and NO_3^- -N concentrations in surface runoff, a paired sample *t*-test was used to identify the differences between the control and the N treatments for each forest. For the NH_4^+ -N and NO_3^- -N concentrations in the soil solution collected at 40 cm depth, with samples collected and analyzed continuously throughout the study period, repeated multivariate analysis was performed to examine the temporal fluctuations in N concentration and univariate analysis was performed to examine the overall N treatment effects. All analyses were conducted using SPSS 10.0 for Windows. Statistical significant differences were set at $P < 0.05$, unless otherwise stated.

RESULTS

N inputs

The N deposition measured as bulk precipitation was $34.2 \text{ kg N ha}^{-1}$ in the study year, 68% of which was in the form of NH_4^+ -N (Table II). NH_4^+ -N inputs *via* throughfall in the two forests were similar; however, NO_3^- -N inputs were significantly higher in the mature forest than in the disturbed forest ($F = 14.1$, $P = 0.006$, Table II). Total N inputs *via* throughfall varied among the collectors from 21.8 to $30.6 \text{ kg N ha}^{-1} \text{ year}^{-1}$ in the disturbed forest and from 31.7 to $51.6 \text{ kg N ha}^{-1} \text{ year}^{-1}$ in the mature forest. After passing through the forest canopy, the importance of NH_4^+ -N declined to be 50% and 47% of the total inorganic N in the disturbed and mature forests, respectively. The N inputs *via* stemflow were low owing to a low amount of water flux (Table II).

TABLE II

Fluxes of water and inorganic N in control plots of disturbed and mature forests in Dinghushan Biosphere Reserve (DHSBR), southern China

Location	Item	<i>n</i>	Water	NH_4^+ -N	NO_3^- -N	Dissolved inorganic N ^{a)}
				kg N ha ⁻¹ year ⁻¹		
DHSBR	Precipitation	3	1 327	23.2	10.9	34.2
Disturbed forest	Throughfall	5	1 140	12.8±0.6 ^{b)}	12.6±1.0	25.4±1.4
	Stemflow	9	13	0.3±0.0	0.5±0.0	0.8±0.1
	Total input	-	1 153	13.1	13.1	26.2
Mature forest	Throughfall	5	1 127	16.5±1.5	18.9±2.5	45.8±4.5
	Stemflow	12	53	0.7±0.1	0.7±0.0	1.4±0.0
	Total input	-	1 180	17.2	19.6	36.8

^{a)} NH_4^+ -N + NO_3^- -N. ^{b)}Means standard errors.

N outputs

Ammonium-N concentration in surface runoff was slightly lower than NO_3^- -N concentration in both forests (Fig. 1). The paired sample *t*-test showed that there was no significant difference in either NH_4^+ -N or NO_3^- -N concentration between the control and N-addition plots in both forests during the study period (Fig. 1). Unlike that in surface runoff, NO_3^- -N concentration in soil solution at 40 cm depth was much higher than NH_4^+ -N concentration in both forests (Fig. 2). In the mature forest, repeated ANOVA for the 11 samplings showed a strong N treatment effect on NO_3^- -N concentration ($F = 15.2$, $P = 0.008$,

Fig. 2d). The average NO_3^- -N concentrations in the control, low N, and medium N plots were 5.4, 13.1, and 10.9 mg L^{-1} , respectively. There was a marginal significant difference in NH_4^+ -N concentration between N treatments ($F = 5.4$, $P = 0.057$, Fig. 2c). The average NH_4^+ -N concentrations in the control, low N, and medium N plots were 0.2, 0.3, and 0.4 mg L^{-1} , respectively. In the disturbed forest, NO_3^- -N concentration also significantly increased with N addition ($F = 9.4$, $P = 0.014$, Fig. 2b) but NH_4^+ -N concentration did not ($F = 2.1$, $P = 0.21$, Fig. 2a). The average concentrations in the control, low N, and medium N plots were 2.7, 6.5, and 7.8 mg L^{-1} for NO_3^- -N and 0.4, 0.7, and 0.7 mg L^{-1} for NH_4^+ -N, respectively.

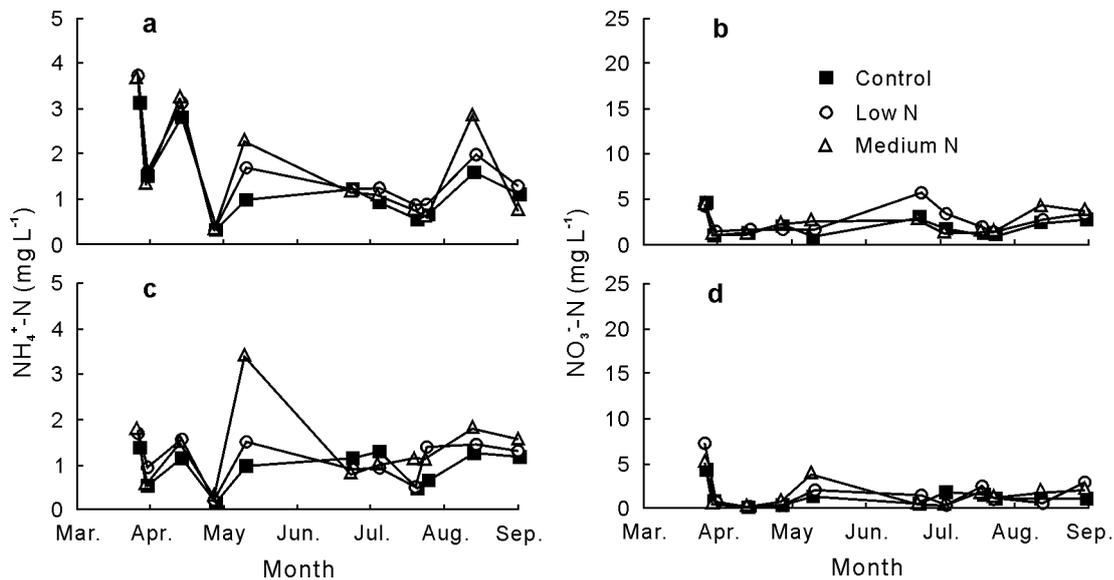


Fig. 1 The concentrations of NH_4^+ -N and NO_3^- -N in surface runoff from disturbed (a and b) and mature (c and d) forests in Dinghushan Biosphere Reserve, southern China.

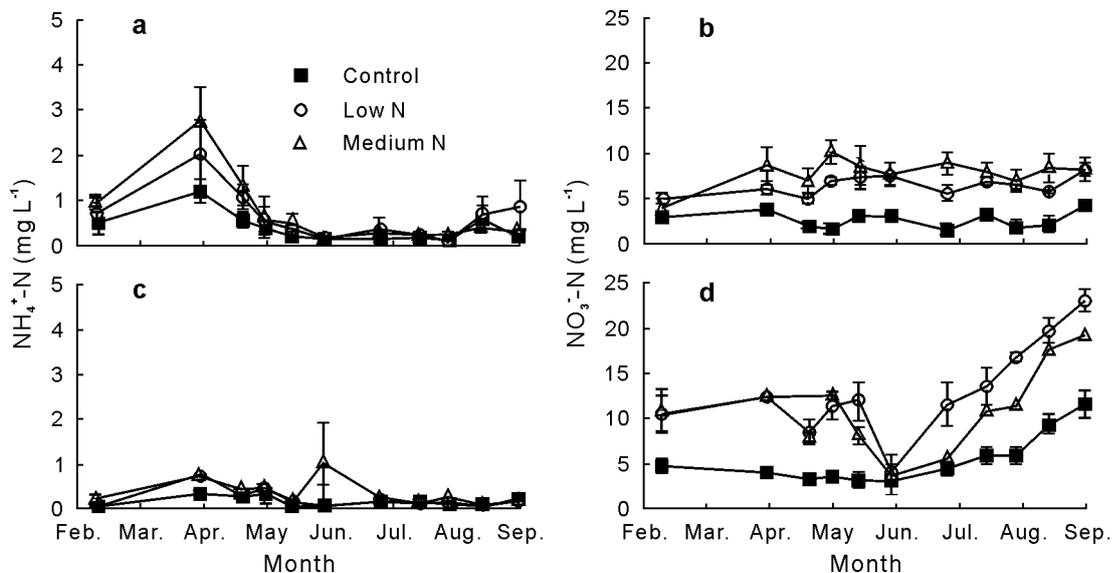


Fig. 2 The concentrations of NH_4^+ -N and NO_3^- -N in soil solution below the rooting zone of the disturbed (a and b) and mature (c and d) forests in Dinghushan Biosphere Reserve, southern China.

The estimated volumes of surface runoff in the study year were 106 and 159 mm and those of leachate below the rooting zone were 345 and 491 mm for the disturbed and mature forests, respectively. The

N leaching loss below the rooting zone was much greater than that *via* surface runoff and accounted for 71%–92% of total N output from the systems, which indicated that N input mainly entered the mineral soil and then leached from the rooting zone.

In the control plots, the total N leaching losses *via* surface runoff and below the rooting zone were 14.6 and 29.2 kg N ha⁻¹ year⁻¹ in the disturbed and mature forests and accounted for 57% and 80% of their corresponding atmospheric inputs (throughfall plus stemflow), respectively (Fig. 3). Both low and medium N treatments substantially enhanced the N leaching losses ($P < 0.01$, Fig. 3). The average increases induced by the addition of 50 and 100 kg N ha⁻¹ year⁻¹ were, respectively, 36.5 and 24.9 kg N ha⁻¹ year⁻¹ in the mature forest, accounting for 73.0% and 24.9% of the annual amount of N added and 14.2 and 16.8 kg N ha⁻¹ year⁻¹ in the disturbed forest, accounting for 28.4% and 16.8% of the annual amount of N added.

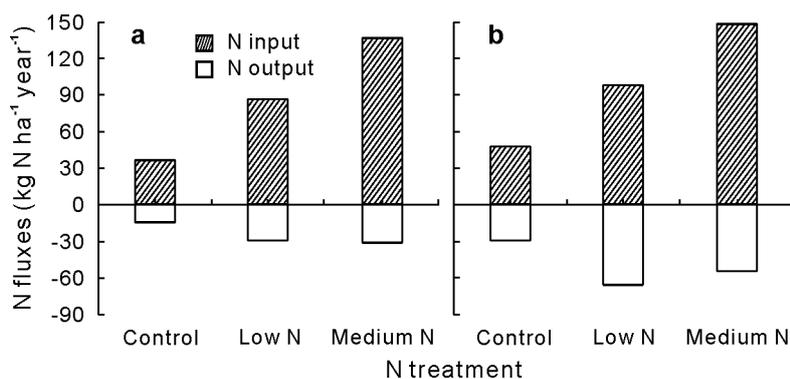


Fig. 3 Input-output fluxes of dissolved inorganic N in pine (a) and mature (b) forests in Dinghushan Biosphere Reserve, southern China. N input referred to the N deposition *via* throughfall and stemflow plus N fertilization; N output referred to the N losses *via* surface runoff plus below the rooting zone.

DISCUSSION

Elevated N leaching from forests is a critical signal of N saturation as defined by Aber *et al.* (1998). Our results in the present study showed that N leaching losses were quite high from the mature forest as expected. The N leaching loss *via* surface runoff and below the rooting zone was measured at 29.2 kg N ha⁻¹ year⁻¹, which accounted for 80% of the atmospheric N inputs (Fig. 3). However, N leaching losses were also found to be high in the disturbed forest. The N leaching losses in this forest was 14.6 kg N ha⁻¹ year⁻¹ and accounted for 57% of the atmospheric N inputs (Fig. 3). The N leaching fluxes from our study forests were within the ranges reported for N saturated forests in North America (0.04–38.9 kg N ha⁻¹ year⁻¹, Fenn *et al.*, 1998) and for 11 sites in Europe receiving N input of greater than 25 kg N ha⁻¹ year⁻¹ (10–35 kg N ha⁻¹ year⁻¹, Dise and Wright, 1995). Thus, both disturbed and mature forests have already been in the relatively high N state and can be characterized as N saturated.

Our results also showed that N leaching losses responded very fast to N additions. The NO₃⁻-N concentration in the soil solution collected at 40 cm depth was constantly higher in the N addition plots than in the control plots for both forests since our sampling started, *i.e.*, after half year of treatment (Fig. 2). The average increase in total N output due to N addition was within 14.2 to 36.5 kg N ha⁻¹ year⁻¹, which accounted for 17%–73% of the annual experimental N addition (Fig. 3). The response of N leaching losses to N additions observed here was apparently faster than those reported for typical N limited temperate forests in both Europe (Emmett *et al.*, 1998; Gundersen, 1998) and North America (Aber *et al.*, 1993; Magill *et al.*, 1996), where both NH₄⁺-N and NO₃⁻-N were retained with high efficiency, leaving little N available for leaching when exposed to ambient or experimentally enhanced N inputs. A typical example is two stands at the Harvard Forest, where very high N retention capacities (95%–100%) to N inputs in the first three years of treatment were shown (Aber *et al.*, 1993), although “nitrate breakthrough” eventually occurred in the most N limited hardwood stand after seven years of treatment

(Magill *et al.*, 2000).

The high N leaching rate and the rapid response to N addition observed in Dinghushan forests may be attributed to local high atmospheric N inputs because relatively low N leaching rates have been observed in two other tropical forests in southern China. Nitrogen export was 6 kg N ha⁻¹ year⁻¹ in a seasonal rain forest in Xishuangbanna, southwest China (Sha *et al.*, 2002), and was only 2.1 kg N ha⁻¹ year⁻¹ in a mountain rain forest in Hainan Island, southern China (Zeng *et al.*, 1997). The measured N inputs in throughfall to the forest reserve ranged from 26 kg N ha⁻¹ year⁻¹ in the disturbed forest to 37 kg N ha⁻¹ year⁻¹ in the mature forest in this study (Table II). These levels were comparable to the highest deposition levels observed in Europe (Dise and Wright, 1995; MacDonald *et al.*, 2002), but were higher than those observed in any forest in North America (Fenn *et al.*, 1998; Campbell *et al.*, 2004) and Japan (Mitchell *et al.*, 1997; Baba *et al.*, 2001; Ohte *et al.*, 2001), as well as in other regions of China (Zeng *et al.*, 1997; Sha *et al.*, 2002). In this study, N input in precipitation was measured as 34.2 kg N ha⁻¹ year⁻¹ in 2004, which is comparable with earlier measurements at Dinghushan, 35.6 kg N ha⁻¹ year⁻¹ in 1990 (Huang *et al.*, 1994) and 38.5 kg N ha⁻¹ year⁻¹ in 1998 (Zhou and Yan, 2001). There was no available data regarding N inputs before 1990 in our study area. Nevertheless, it is certain that the Dinghushan forest has been experiencing a high N deposition level greater than 30 kg N ha⁻¹ year⁻¹ for at least 15 years. This means that the Dinghushan forest has received more than 450 kg N ha⁻¹ in total N over this period, which is very likely to saturate a forest ecosystem with N, particularly in tropical environments. A survey of N output from 65 forested plots and catchments throughout Europe showed that sites receiving N inputs above 25 kg N ha⁻¹ year⁻¹ all leached significant quantities of N (Dise and Wright, 1995). Many N addition experiments carried out in both European and North America forests have demonstrated that N saturation could be induced by chronic N additions in previous N limited systems (Kahl *et al.*, 1993; Moldan *et al.*, 1995; McNulty *et al.*, 1996; Magill *et al.*, 2000; Rueth *et al.*, 2003). Our conclusion was also confirmed by another study in Guangzhou, about 100 km east of our study site, where N leaching rate was within 10.0–13.3 kg N ha⁻¹ year⁻¹ at 40 cm soil depth in three forests receiving high N loads of 24–70.6 kg N ha⁻¹ year⁻¹ in throughfall (Xu *et al.*, 2001).

The disturbed pine forest originated from the 1930's clear-cut and pine plantation had been under constant human disturbance during 1930 to 1998. Thus, this forest is likely to be actively accumulating organic matter and N after stopping harvesting activities. Nevertheless, in this study, the disturbed forest is unexpectedly found with a high N leaching loss rate and a fast response of N leaching to N additions. We suspect that the previous disturbance is another possible contributing factor in addition to receiving higher local atmospheric N inputs. The disturbance was generally harvesting of understory plants and litter about twice to thrice yearly (Mo *et al.*, 1995; 2003), which would inevitably result in some negative effects on the ecosystem. First, the harvesting removed the nutrients that should cycle back to the soil (Mo *et al.*, 1995), and consequently reduced the plant need for N. Second, the harvesting has reduced soil organic matter content through decreasing organic matter inputs (Mo *et al.*, 1995; Brown *et al.*, 1995), which is usually shown to be the largest pool to retain added N. In a survey of 29 N fertilization studies, an average of 39% of the added N was recovered in the soil compared with 28% in the vegetation (Johnson and Lindberg, 1992). In the ¹⁵N tracer studies summarized by Fenn *et al.* (1998), 30%–87% of the labeled NH₄⁺ was retained in soil and 6%–33% was recovered in vegetation. Of the labeled NO₃⁻ applied to forest ecosystems, 19%–86% was retained in soil and 4%–37% was recovered in vegetation. The differences in soil bulk density and soil organic carbon concentration between the disturbed and mature forest have indicated that the depletion of soil organic matter may have occurred in the disturbed forest after the clear-cut and the subsequently continued disturbance (Table I). Finally, the harvesting activities may have increased the rate of N cycling in the ecosystem and subsequent potential of N leaching because it was reported that the harvesting of litter and understory increased soil available mineral N in this site (Mo *et al.*, 2003).

The results for the disturbed forest have a great implication in southern China. There are large areas of pine forests in this region (Brown *et al.*, 1995; Mo *et al.*, 2003, 2004) and this region has been

experiencing an increasing N deposition (Xu *et al.*, 2001; Chen *et al.*, 2004). In China, most of the lands originally covered with primary forests have been degraded by human activities during the past several hundred years. In extreme cases, the land became completely non-vegetated (Brown *et al.*, 1995). Chinese deforestation is estimated to be in the order of 0.61 million ha per year during the 1990s and the remnant native mature forest area now is less than 9% of total territory (Liu *et al.*, 2000). Attempts to reverse this process of land degradation have been initiated in southern China. Over the last several decades, large areas have been reforested with a native pine species (*P. massoniana*) to prevent further degradation of the landscape. Cutting of the trees is now prohibited, but harvesting of understory and litter is allowed to satisfy local fuel needs. These rehabilitated forests (reforested but no harvesting) and the disturbed forests cover more than half of the total forest area in southern China (Mo *et al.*, 2003). However, the effects of these significant land-use changes on the ecosystem processes are poorly known (Mo *et al.*, 2003), and no information is available regarding the ecosystem response to increasing N deposition in human disturbed forest ecosystems. Our results demonstrated that the disturbed pine forest exhibited great N leaching losses and a fast N leaching response to experimental N additions. We can thereby conclude that some of pine forests in this region may also have been N saturated, similar to the disturbed forest we studied in Dinghushan Biosphere Reserve. This also implied that the large area of pine forest in the region may be sensitive to increasing N deposition.

CONCLUSIONS

The disturbed pine and mature forests in the Dinghushan Biosphere Reserve of southern China received a high N deposition load. Both disturbed and mature forest types leached considerable amount of nitrate under ambient N input, and N leaching losses increased rapidly with additional N inputs. The mature forest exhibited great N leaching and a fast response, which might result from long-term N accumulation and high ambient N deposition load. However, in the disturbed forest, it might be attributed to the human disturbance and high ambient N deposition load. Our results implied that both mature and disturbed forests in the study region may be sensitive to increasing N deposition.

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