The Impacts of Excessive Nitrogen Additions on Enzyme Activities and Nutrient Leaching in Two Contrasting Forest Soils

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Nitrogen (N) deposition has increased dramatically worldwide, which may affect forest soils in various ways. In this study, we conducted a short-term manipulation experiment of N addition on two types of forest soils (urban and rural soils) found in Korea. N addition significantly decreased phenol oxidase activities in urban soil samples; however, it did not affect those in rural soils. Furthermore, N addition did not change ß-glucosidase and N-acetylglucosaminidase activities, except for ß-glucosidase activities in the O layer of rural soils. Changes in microbial biomass and general activity (dehydrogenase activity) were not induced by N addition, except for dehydrogenase in the A layer of urban soils. Although N addition did not change the extractable soil nutrients, organic matter, and water contents significantly, it enhanced nutrient leaching and resulted in lower pH leachate. These results suggest that excessive N addition to forest soils may induce nutrient leaching in the long-term. Overall results of our study also suggest that N addition may induce retardation of organic matter decomposition in soils; however, such a response may depend on the intensity of previous exposure to N deposition.

Keywords: nitrogen deposition, microbial enzyme activity, soil acidification, temperate forest

Nitrogen (N) deposition from the atmosphere has increased rapidly due to anthropogenic activities such as intensive agriculture and increases in automobile emissions (Holland et al., 1999). East Asian countries including Korea are exposed to high N deposition, comparable to European and North American countries (Galloway, 1998; Bashkin et al., 2002). For example, N deposition in Seoul is reported to be 2.9 to 3.2 g N·m⁻²·yr⁻¹, which is slightly higher or comparable to southern Nevada in USA (2.0 to 3.5 g N·m⁻²·yr⁻¹) and Wales in the UK (2.0 to 2.5 g N·m⁻²·yr⁻¹) (Park, 1999). However, there is little information about the impact of N deposition on forest soils in Asian regions.

Since N has been considered a limiting nutrient for terrestrial ecosystems in general, an increase in N deposition was believed to cause positive effects on forest ecosystems through fertilization (Aber et al., 1991). In particular, excessive N deposition can raise the content of foliar N through plant uptake, which may reinforce the activity of ribulose disphosphate carboxylase and hence increase photosynthetic rates and primary production (Schlesinger, 1997).

However, an adverse impact of excessive N addition was noted in many European and North American countries experiencing forest decline in the early 1980s (Van Dijk and Roeloffs, 1998). According to the ‘Nitrogen Saturation’ hypothesis proposed by Aber et al., (1989), added N is absorbed by microbes and plants at an early stage, so that the primary production of microbes and plants tends to increase. However, the long-term addition of excessive N can delay decomposition rates of recalcitrant organic matter due to the inhibition of lignin-degrading enzymes (Carreiro et al., 2000; Micks et al., 2004). As a result, the impeded decomposition rate leads to an insufficient supply of nutrients for microbes and vegetation, accompanied with weakened growth and reduced primary production. The accumulated phenolic material, in turn, could inhibit other enzyme activities related to the degradation of organic matter, which would further limit the nutrient supply for microbes and plants (Wetzel, 1992; Kang and Freeman, 1999).

However, more recent studies conducted in the 2000s have noted that N deposition along with elevated CO2 have accelerated forest growth, resulting in the retention of 30% of N applied to forests. Further, a similar amount of N is known to be retained in forest soils (Schlesinger, 2009). We hypothesize that such high retention of N in forest soils is related to a decrease in organic matter decomposition and lower enzymatic activity. In addition, the intensity of inhibitory effects of N addition is expected to differ between soils with different historical exposure to N deposition. For example, areas that have already been exposed to high N deposition (e.g., urban soils) may be more negatively affected by N addition than rural soils. To test this hypothesis, we collected soil samples from two forest soils with different N deposition and conducted a short-term N addition experiment.

Materials and Methods

Site description and soil samplings

The first soil sample was collected at Mt. Nam, Seoul, South Korea, located in the central part of Seoul (39°32' N, 126°08' E). Being located in the center of the city, this area has been exposed to a large amount of N deposition (NO₃⁻ and NH₄⁺, 1008 eq/ha/yr) (Park, 1999).
Vegetation is dominated by Mongolian oak (*Quercus mongolica*), pines (*Pinus sargentii, P. densiflora*) and five afforestations including *Robinia pseudo-acacia, Populus tomentoglandulosa, P. korensis, P. rigida*, and *Metasequoia glyptostroboides* (Lee et al., 1998). The second set of soils was sampled at Mt. Jumbong in Kangwon-Do, South Korea (38°02' N, 128°06' E), which is a well-protected and pristine area with much lower N deposition (456 eq·ha⁻¹·yr⁻¹). The dominant vegetation consists of temperate mixed-hardwood Korean maple (*Acer pseudo-sieboldianum*) and Mongolian oak (*Quercus mongolica*). The texture of both sites is sandy loam and loamy sand. Each soil sample was collected from the O and A layers. In order to exclude vegetation effects, soils were collected at least 2 m away from vegetation and sampled soils were transferred to a laboratory on ice.

**Experiment design**

Soil samples were sieved (2 mm) and placed in PVC cores in the

![Fig. 1. Influence of N addition on phenol oxidase (A and B), β-glucosidase (C and D), and N-acetylglucosaminidase (E and F) in urban (left panel) and rural (right panel) forest soils in Korea. Bars labeled with different letters are significantly different from each other (one-way ANOVA, P<0.05).](image-url)