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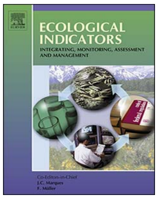

Original Articles

Soil nitrogen supply capacity as an indicator of sustainable watershed management in the upper basin of Miyun Reservoir

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ABSTRACT

Comprehensive evaluation of soil N supply capacity is a fundamental approach to reduce N pollution. In this research, we developed a novel framework to quantify soil N supply capacity. This was accomplished by integrating a multivariate regression analysis and a path analysis to establish the relationship between the amount of soil supplied N and six main processes (i.e., organic N mineralization, atmospheric N deposition, litter decomposition, nitrification, denitrification and surface runoff) related to soil N cycle, with exclusion of the multi-collinearity among these six main processes. Soil N supply capacity was measured by the ratio of soil supplied N and plant required N. The results revealed that (1) organic N mineralization was the dominant process that sustained the amount of soil supplied N, contributing 81.51–121.54 kg N/hm^2 a under different land utilization patterns; (2) processes such as atmospheric N deposition, litter decomposition and surface runoff could affect the amount of soil supplied N as well. In detail, atmospheric N deposition contributed 11.88–27.79 kg N/hm^2 a to soil supplied N. Litter decomposition in coniferous, broadleaf and mixed forests provided 57.31–59.26 kg N/hm^2 a to soil supplied N, which accounted for over half of the N provided by organic N mineralization. Surface runoff reduced soil supplied N by about 14.78% (73.57 kg N/hm^2 a) in the shrub forest; (3) soil N supply capacity under different land use types ranged from 1.43 to 8.30, indicating sufficient fertility for plant growth and an insistent demand for soil N management.

1. Introduction

Nitrogen (N) is a major limiting factor for the growth of plants (Cui et al., 2013; Mao et al., 2017). Over the last several decades, though artificial fertilizer is widely utilized, crop yield still mainly depends on the sustaining supply of nitrogen from indigenous soils (George, 1982; Kurwakumire et al., 2014; Mungai et al., 2016). Thus, soil nitrogen supply capacity is a key factor for maintaining agricultural productivity. This capacity is of increasing concern more recently due to public concerns over many side effects of artificial fertilizers (Tan et al., 2011) and the rising demands for organic foods. A systematic assessment of the inherent N supply capacity from the soil benefits not only to safe agricultural production but also to the protection of ecosystems and the environment (Cai et al., 2010; Hu et al., 2014).

Previously, the majority of soil N supply capacity assessment studies were based on short-term incubation experiments under a series of controlled laboratory conditions (Maynard, 1993; Mohanty et al., 2013). They mainly focused on the mineralization process of soil organic N that can covert the labile fraction of soil N into multiple mineral forms (e.g., NH_4^+, NO_2^- and NO_3^-) through a variety of microbial activities. Thus mineralized N is considered the primary contributor to the soil supplied N (Curtin and Mccallum, 2004; Agehara and Warncke, 2005; Spargo et al., 2016), which plays a significant role in providing N for plant uptake and crop growth within a soil-plant system (Power, 1980; Mikha et al., 2006; Judith et al., 2012; Thomas et al., 2015). As pioneering researchers in the assessment of soil N supply capacity, Stanford and Smith (1972) defined the soil N that could potentially be mineralized (i.e., N_0) as the quantification of soil organic N susceptible to mineralization which was a first-order kinetic process at a specific rate constant (i.e., k). Since then, the first-order kinetic model has been regarded as a standard method to estimate N mineralization potential and the associated constant rate of mineralization (Schomberg et al., 2009; Mervin et al., 2011), as well as N supply capacity of the soil (Griffin et al., 2008; Cavalli et al., 2016). To remedy the deficiency of the first-order kinetic model in reflecting and tackling the heterogeneity of soil properties, a double exponential model was proposed by a few researchers. They combined two first-order kinetic models to reflect two separate N pools (i.e., the active and slow

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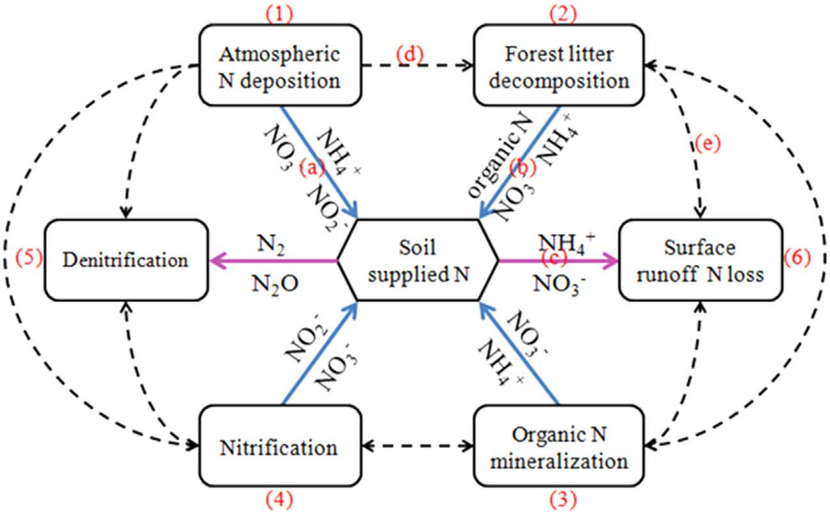

Fig. 1. Main components, processes and factors of soil N cycle.Note: (1) = atmospheric N deposition process(2) = forest litter decomposition process(3) = organic N mineralization process(4) = nitrification process(5) = denitrification process(6) = surface runoff N loss process(a) = interaction between air and soil(b) = interaction between plants and soil(c) = interaction between water and soil(d) = interaction between air and plants(e) = interaction between plants and water

mineralization pools) in sequence within the study soils (Wang et al., 2004; Gilmour, 2011; Dessureault-Rompre et al., 2015).

In aggregate, soil mineralizable N is a major pool for sustaining N supply in soils. Previously, the amount of mineralizable N was merely estimated through incubation experiments under a number of controlled laboratory conditions. However, a single N factor (i.e., soil mineralizable N) is insufficient to represent the soil N supply capacity at a local scale, because some important and inherent processes such as atmospheric N deposition (Ochoa-Hueso et al., 2014), litter decomposition (Silva et al., 2013), surface runoff (Diaz et al., 2011), as well as nitrification (Chinnadurai et al., 2014; Fiorentino et al., 2016) and denitrification (Yang et al., 2015) have been proved to be closely related to soil supplied N. Hence, a combination of multiple N processes that operate in conjunction with soil N cycle would be beneficial for assessing soil N supply capacity comprehensively.

In this research, we use published literature data to develop a novel framework for comprehensively evaluate and quantify soil N supply capacity based on the detailed quantification of six main processes within three components (i.e., air, soil and plants) related to soil supplied N (Fig. 1). In detail, major components, processes and factors are to be screened out; a combination of multivariate regression and path analysis will be applied to reveal the multi-collinearity among soil variables and exclude the relevant soil variables for assessing soil N supply capacity; and a combination of the quantification of the six processes will reflect the comprehensive process of soil N cycle and identify the corresponding soil N supply capacity. This study represents an innovation upon the previous studies in the following aspects: a) integrity of soil N supply capacity evaluation can be improved based on multiple components and multiple processes related to soil N cycle, b) the key factors affecting soil N supply can be identified with exclusion of their overlaps.

2. Methodology

2.1. Study area

The Tumenxigou watershed is located in Miyun County of Beijing with an area of 3.49 km^2 and is 5 km away from the east of the Miyun Reservoir, which is the primary drinking water source for the city of Beijing. The main landforms of the watershed include hills and low mountains. The leached cinnamon soil is the dominant cultivated layer that is distributed in most of the watershed with an approximate depth of 50 cm. The studied watershed belongs to a warm temperate continental monsoon climate, characterized by significant winds and distinct seasons. The annual precipitation in this watershed changes dramatically, ranging from 242 to 1406 mm with an average of 669 mm. Most of the rainfall occurs from June to September in the form of intense rainstorms, which account for 80–85% of the total precipitation within a year. Land use types in this region include terraced field, as well as coniferous, broadleaf, mixed, shrub, and production forests (Table 1).

2.2. Equations to quantify the main processes affect soil supplied N

2.2.1. Atmospheric N deposition

$$N_{AC} = 1.132 \times e^{0.212x} (r^2 = 0.743) \tag{1}$$

where N_{AC} is the N input through atmospheric deposition to soils in coniferous forests, kg N/hm^2 a; x is the N content in precipitation, kg N/hm^2 a; e is the base of the natural logarithm; r is the related coefficient for throughfall N and precipitation N.

$$N_{AB} = 1.55 \times e^{0.146x} (r^2 = 0.850) \tag{2}$$

where N_{AB} is the N input through atmospheric deposition to soils in broadleaf forests, kg N/hm^2·a; x is the N content in precipitation, kg N/hm^2 a; e is the base of the natural logarithm; r is the related coefficient for throughfall N and precipitation N.

2.2.2. Litter decomposition

$$N_L = \beta \times M_0 \times (1 - e^{-kt}) \tag{3}$$

where N_L is the N input through litter decomposition, kg N/hm^2 a; β is the content of N in the litter, g N/kg; M_0 is the initial mass of litter available to be decomposed, t/hm^2; e is the base of the natural logarithm; k is the constant of the decomposition rate; t is the

Table 1
Land use types in the study area.

Land use types	Main vegetation	S(hm^2)
Coniferous forest	chinese pine	81
Broadleaf forest	robinia	52
Mixed forest	robinia, pine, vervain family	49
Shrub forest	vervain family	14
Production forest	chestnut, walnut	128
Terrace field	corn	26