forests

Article

Effects of Tourism Trampling on Soil Nitrogen Mineralization in *Quercus variabilis* Blume Forests Varies with Altitudes in the Climate Transition Zone

Qing Shang [1], Yanchun Liu [2,*] and Qinglin Li [2]

1 Yellow River Conservancy Technical Institute, Kaifeng 475004, China
2 School of Life Sciences, Henan University, Kaifeng 475004, China
* Correspondence: liu_yan_chun@126.com; Tel.: +86-371-2388-5016

Abstract: Tourism trampling is one of the critical disturbance factors affecting forest structure and function apart from forest management activities. However, how tourism trampling affects soil nitrogen (N) mineralization rate at different altitudes in scenic forest spots is still unclear. To determine whether the responses of soil net N mineralization rate to tourism trampling varies with altitudes, we incubated soils using a field buried pipe method and analyzed soil ammonium N (NH_4^+-N) and nitrate N (NO_3^--N) content at three altitudes (810 m, 1030 m, and 1240 m) at the Baotianman forest scenic spot in Henan Province. The results showed that tourism trampling significantly increased the soil bulk density and soil pH value but substantially reduced soil organic carbon (C) and total N content at all altitudes. Tourism trampling also resulted in a significant decrease in NO_3^--N in the soil before and after incubation at all altitudes. The effects of tourism trampling on soil net N mineralization varied with latitudes, showing positive effects at 1030 m altitude (+51.4%), but negative effects at 1240 m altitude (−43.5%). For the soil net N nitrification rate, however, tourism trampling resulted in an increased rate (+141.1%) only at the 810 m altitude. Across all altitudes, soil microbial biomass C is primarily responsible for the variation in the soil net N mineralization rate. This study indicates that the effect of tourism trampling on soil net N mineralization rate varies with altitudes, which is related to the intensity of tourist disturbance and the synthetic effects of vegetation and soil microbes.

Keywords: altitudinal gradient; available nitrogen; microbial biomass carbon; nitrogen nitrification; tourism disturbance

Citation: Shang, Q.; Liu, Y.; Li, Q. Effects of Tourism Trampling on Soil Nitrogen Mineralization in *Quercus variabilis* Blume Forests Varies with Altitudes in the Climate Transition Zone. *Forests* **2022**, *13*, 1467. https://doi.org/10.3390/f13091467

Academic Editors: Anna Zavarzina, Irina N. Kurganova, Yakov Kuzyakov, Francisco Matus, Agustin Merino and Wenhua Xiang

Received: 18 August 2022
Accepted: 6 September 2022
Published: 12 September 2022

1. Introduction

Soil nitrogen (N) availability is one of the key environmental factors regulating plant growth and ecosystem productivity [1,2]. More than 90% of soil N exists in the form of organic N, which cannot be directly absorbed and utilized by plants [3]. Therefore, soil N availability for plants is largely determined by the transformation rate from organic N to inorganic N [4], which is driven by soil microbes through microbial mineralization [5]. Soil available N mainly includes ammonium N (NH_4^+-N) and nitrate N (NO_3^--N). Soil N mineralization rate determines the proportion and quantity of each of the two components, thus regulating the availability of soil N further. The mineralization process of soil organic N is a biogeochemical cycle driven by soil microorganisms and many biological and abiotic factors [6].

Generally, plant activities [7], microbial metabolism [6,8], soil fauna activities [9], and soil microclimate [10] are the main environmental factors regulating the soil N mineralization rate. Trampling-related activities and processes generated by the foraging of wild animals [11], the grazing of livestock [12], and human leisure tourism [13] show significant influences on soil physical structure, microbial community, nutrient cycle, and other ecological functions [14] in the forest ecosystems. Therefore, trampling disturbances that can directly lead to the changes in soil texture are also an important biological factor regulating the soil N mineralization rate [15,16].

With the continuous improvement in living standards, periodic tourism activities have become one of the necessities for people's daily life. Trampling disturbance caused by tourism activities may directly result in the deaths of some plants adjacent to the tourist trails [17]. Meanwhile, it can also cause soil compaction [18], thus resulting in a decline in the aesthetics of scenic spots. This kind of tourism trampling is particularly common in scenic forest and grassland spots where tourist trails are not covered with cement. Therefore, tourism trampling has become an important factor affecting ecosystem service functions [9]. Previous studies have confirmed that tourism trampling can alter soil physical structure, microbial community structure, nutrient content, and soil enzyme activity in most scenic spots [13,18,19]. As one of the important links in soil nutrient turnover, however, it remains unclear how soil N mineralization and nitrification rates respond to tourism trampling, and whether the potential mechanism varies with altitudes.

In this study, we conducted a paired experimental design (tourist trampling/no trampling) at three altitudes (810 m, 1030 m, and 1240 m) and investigated the soil NH_4^+-N and NO_3^--N content before and after the field incubation in an oak-dominated forest at Baotianman forest scenic spot in Henan Province. We hypothesized that (i) the soil N net mineralization rate at the site without trampling would decrease with the elevated altitudes due to the reduced soil temperature; (ii) tourism trampling would decrease the soil N net mineralization rate due to the increased soil compaction at all altitudes. Specifically, we aimed to answer the following questions: (1) How does tourism trampling affect the soil N net mineralization rate at different altitudes? (2) How do environmental factors mediate the effects of tourism trampling on the soil N net mineralization rate?

2. Materials and Methods

2.1. Study Site

The study site is located in the Baotianman Forest Ecosystem Research Station (111°47′–112°04′ E, 33°20′–33°36′ N) at the south foot of Funiu Mountain in Nanyang City, Henan Province. The highest peak of Baotianman reaches 1830 m. The climate type is characterized by an East Asian monsoon climate with four distinct seasons and showing a synchronism for the water and heat. The mean annual precipitation is 856 mm, and the mean annual temperature is 15.1 °C. Benefiting from the subtropical humid climate, there are numerous vegetation types, including evergreen broad-leaved forest, deciduous broad-leaved forest, and mixed evergreen–deciduous broad-leaved forest.

2.2. Experimental Design

Four experimental areas were conducted for each of the three altitudes (810 m, 1030 m, and 1240 m) at Baotianman in June 2019. At each altitude, the 4 experimental areas were randomly distributed with an interval of more than 50 m. All experimental areas have similar features in terrain, slope, and soil texture, and the slope is less than 10°. The dominant tree species, distributed at all altitudes, is *Quercus variabilis* Blume, and the dominant species of understory shrubs are *Lindera glauca* (Sieb. et Zucc.) Bl), *Vitex negundo* L., and *Acer buergerianum* Miq.

The study used a paired experimental design. In each experimental area, a forest path formed by tourists' trampling was selected as the trampling area, which is mainly characterized by the obvious trampling, soil surface hardening, and no shrub and grass growth. A 3 m × 3 m plot was set up randomly in each trampling site as the trample plot. Within the range of 5–10 m from each trampling plot, an unperturbed plot (3 m × 3 m) was established as the control (non-trample), showing the features without obvious human interference and trampling. It is characterized by a thickened litter layer on the surface, developed soil natural structure, and vigorous growth of shrubs and herbs.

2.3. Soil Sampling and Analysis

Since summer is the peak period of tourist reception at Baotianman, we conducted our experiment from June to July. Three soil cores (5 cm diameter × 10 cm depth) were randomly collected and mixed in each plot using a hand auger at the end of June. After passing a 2 mm soil sieve, a part of fresh soil is air dried to determine the soils' physical-chemical properties; another part of the fresh samples was stored at −20 °C to determine soil microbial biomass carbon (C) (MBC) and N (MBN). The air-dried soil sample was further sieved by 250 μm mesh to investigate soil organic C and total N using dichromate oxidation and Kjeldahl digestion [20,21], respectively. Soil MBC and MBN were determined by the chloroform-fumigation-extraction method introduced by [22,23]. During the collection of soil samples, soil bulk density of 0–10 cm was measured using a stainless-steel cutting ring (5 cm in diameter and 5 cm in height).

The soil net N mineralization rates were estimated in situ using polyvinyl chloride (PVC) tubes (5 cm in diameter and 10 cm in depth). In each plot, six PVC tubes were vertically inserted into the soil for 10 cm at intervals of 10–15 cm. Soil samples from three tubes were collected for initial NH_4^+-N and NO_3^--N analysis. Soil samples from the remaining tubes were retrieved and analyzed after 30 days of field incubation. All fresh soil samples were passed through a 2 mm soil sieve and transported to the laboratory for further analysis. Soil NH_4^+-N and NO_3^--N content were determined using a Discrete Auto Analyzer (SmartChem 200, WestCo Scientific Instruments Inc., Brookfield, CT, USA). The soil pH value was measured by the potentiometric method (water: soil = 2.5:1).

2.4. Data Analysis

The soil N net mineralization and nitrification rates were calculated according to the differences in NH_4^+-N and NO_3^--N contents before and after the in situ incubated soil and the incubation time (days). The calculation equations [10] were as follows:

$$R_m = \left[\left(\mathrm{NH_4^+} - \mathrm{N}\right)_{t+1} + \left(\mathrm{NO_3^-} - \mathrm{N}\right)_{t+1} - \left(\mathrm{NH_4^+} - \mathrm{N}\right)_t - \left(\mathrm{NO_3^-} - \mathrm{N}\right)_t \right] / (T_{t+1} - T_t) \tag{1}$$

$$R_n = \left[\left(\mathrm{NO_3^-} - \mathrm{N}\right)_{t+1} - \left(\mathrm{NO_3^-} - \mathrm{N}\right)_t \right] / (T_{t+1} - T_t) \tag{2}$$

where Rm and Rn represent soil N net mineralization rate and net nitrification rate ($\mathrm{mg \cdot kg^{-1} \cdot d^{-1}}$), respectively; NO_3^--N and NH_4^+-N refer to soil nitrate N and ammonium N content; t refers to the initial sampling; t+1 refers to the final sampling after in situ incubation; and T refers to the interval between sampling (days).

The content of soil inorganic N is the sum of soil nitrate N and ammonium N. Based on the test of normality and homogeneity of variance of the data, the effects of altitude and trampling on the soil N net mineralization rate were tested using a two-way ANOVA, and the statistical significance of the differences in the soils' physical-chemical variables and the soil N net mineralization and nitrification rates between trample and non-trample at each altitude gradient were further tested by a one-way ANOVA. Statistical analysis of the data was performed in SPSS 26.0 software (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Soil Physical-Chemical Characteristics

The soil pH tended to be acidic, ranging from 4.05 to 4.46. Soil pH value showed no obvious pattern with the elevated altitude. The pH value under the trampled soil (4.22–4.46) was significantly higher than that under the non-trampled soil (4.05–4.25), showing a significant difference at 1240 m ($p < 0.05$, Table 1). In addition, the pH value under trampled soil at 1240 m altitude was significantly higher than that at 810 m and 1030 m altitudes ($p < 0.05$, Table 1).

Table 1. Effects of tourist trampling on soil physical and chemical properties (mean ± S.E.).

Altitude (m)	Site	pH	Soil Bulk Density ($g \cdot cm^{-3}$)	Soil Organic C ($g \cdot kg^{-1}$)	Total N ($g \cdot kg^{-1}$)
810	Trampled	4.28 ± 0.03 b	1.32 ± 0.16 a	29.65 ± 2.44 b	2.13 ± 0.07 d
	Non-trampled	4.12 ± 0.08 bc	1.02 ± 0.08 bc	34.16 ± 4.87 a	2.24 ± 0.12 cd
1030	Trampled	4.22 ± 0.05 bc	1.18 ± 0.11 b	26.91 ± 3.11 bc	2.37 ± 0.11 bc
	Non-trampled	4.05 ± 0.09 c	0.99 ± 0.13 bc	28.27 ± 2.16 b	2.44 ± 0.06 b
1240	Trampled	4.46 ± 0.11 a	1.03 ± 0.06 bc	21.47 ± 1.33 c	2.26 ± 0.11 ab
	Non-trampled	4.25 ± 0.14 bc	0.82 ± 0.17 d	24.16 ± 1.79 bc	2.51 ± 0.09 a

Different lowercase letters indicate significant differences between means of all treatments within each column at the 0.05 level.

With the increased altitude, the soil bulk density showed a gradual downward trend for both trampled and non-trampled soils. The soil bulk density at the trampled plots ranged from 1.03 to 1.32 g cm^{-3}, which is significantly higher than that at the non-trampled plots (0.82–1.02 g cm^{-3}) ($p < 0.05$, Table 1) for all three elevations. Soil organic C at both trampled and non-trampled plots decreased gradually with the increased altitude. For plots without trampling, soil organic C (34.16 $g \cdot kg^{-1}$) at 810 m altitude was significantly higher than that at 1030 m (28.27 $g \cdot kg^{-1}$) and 1240 m (24.16 $g \cdot kg^{-1}$) ($p < 0.05$, Table 1). For plots with trampling, soil organic C (29.65 $g \cdot kg^{-1}$) at 810 m altitude was significantly higher than that at 1240 m (21.47 $g \cdot kg^{-1}$); however, there was no significant difference between 810 m and 1030 m (Table 1).

Soil total N content for plots without trampling showed a significant increasing trend with the elevated altitude, and values at the high altitude were significantly greater than that at low altitude ($p < 0.05$). For plots with trampling, however, soil total N content showed no change with the increased altitude. Total N content of the trampled soil at the altitude of 810 m was significantly lower than that at the altitude of 1030 m and 1240 m. Regardless of the altitude, soil total N content under trampling (2.13–2.37 $g \cdot kg^{-1}$) was lower than that under non-trampling (2.24–2.51 $g \cdot kg^{-1}$; Table 1).

The effect of tourism trampling on soil NO_3^--N content varied with altitude ($p < 0.05$, Table 2). At 810 m, the soil NO_3^--N content at the trampled plots was 7.94 $mg \cdot kg^{-1}$, which is significantly lower than that at the non-trampled plots (20.31 $mg \cdot kg^{-1}$). At 1030 m, trampling led to a weak decrease in soil NO_3^--N content; nevertheless, trampling led to a slight increase in soil NO_3^--N at 1240 m (Table 2). Similar to the change in soil NO_3^--N content, soil inorganic N content decreased significantly with the increased altitudes (Table 2), and trampling led to a significant decrease of 31.3% in inorganic N content at 810 m altitude ($p < 0.05$, Table 2). After 30 days of field incubation, the soil NO_3^--N content for both trampled and non-trampled soils increased significantly with the elevated altitude ($p < 0.05$, Table 2). At the altitude of 810 m, the soil NO_3^--N content of the trampled soil (19.78 mg·kg−1) was significantly lower than that of the non-trampled soil (25.23 $mg \cdot kg^{-1}$) ($p < 0.05$, Table 2).

Table 2. Changes in soil NO_3^--N, NH_4^+-N, and total inorganic N induced by tourism trampling at different altitudes (mean ± S.E.).

Altitude (m)	Site	June			July		
		NO_3^--N ($mg \cdot kg^{-1}$)	NH_4^+-N ($mg \cdot kg^{-1}$)	IN ($mg \cdot kg^{-1}$)	NO_{3-}-N ($mg \cdot kg^{-1}$)	NH_4^+-N ($mg \cdot kg^{-1}$)	IN ($mg \cdot kg^{-1}$)
810	Trampled	7.94 ±1.9 d	17.36 ±1.36 a	25.31 ±1.45 c	19.78 ±1.52 e	16.08 ±0.34 bc	35.86 ±1.35 c
	Non-trampled	20.31 ±1.22 c	16.53 ±1.36 a	36.84 ±1.33 b	25.23 ±1.35 d	20.36 ±1.86 a	45.59 ±3.18 b
1030	Trampled	21.24 ±0.42 c	16.27 ±3.19 a	37.51 ±3.32 b	29.77 ±2.8 cd	18.12 ±2.22 ab	47.89 ±2.77 b
	Non-trampled	22.63 ±0.24 bc	18.71 ±0.46 a	41.35 ±0.57 ab	31.86 ±1.89 bc	16.34 ±0.33 bc	48.21 ±1.76 ab
1240	Trampled	26.65 ±0.65 a	16.36 ±0.6 a	43.01 ±1.05 a	36.71 ±2.15 ab	14.08 ±0.75 c	50.79 ±1.89 ab
	Non-trampled	24.4 ±1.84 ab	15.61 ±0.94 a	40.01 ±2.64 ab	38.21 ±2.71 a	15.58 ±0.7 bc	53.79 ±2.26 a

Different lowercase letters indicate significant differences between means of all treatments within each column at the 0.05 level.

Neither altitude nor trampling showed a significant effect on soil NH_4^+-N content in June. After incubation, the soil NH_4^+-N content decreased significantly with the increased altitude ($p < 0.05$, Table 2), from 18.22 mg·kg^{-1} at 810 m to 14.83 mg·kg^{-1} at 1240 m. The soil NH_4^+-N content under trampling at 810 m was significantly higher than that at 1030 m and 1240 m. In addition, soil NH_4^+-N content at the trampled plots at 1030 m was significantly higher than that at 1240 m (Table 2). Soil inorganic N content increased significantly with the elevated altitude ($p < 0.05$, Table 2). The content of soil inorganic N (35.86 mg·kg^{-1}) under trampling at 810 m altitude was significantly lower than that at 1030 m and 1240 m. Moreover, trampling resulted in a significant decrease of 21.3% in soil inorganic N content at 810 m (Table 2).

3.2. Soil N Net Mineralization and Nitrification Rate

A two-way ANOVA showed that the effect of trampling on the soil N net mineralization and nitrification rate varied with altitude gradients (Figure 1). For soils without trample, the net mineralization rate (0.459 mg·kg^{-1}·day^{-1}) at 1240 m altitude was significantly higher than that at 810 m and 1030 m altitude ($p < 0.05$). However, the net N mineralization rate of the trampled soil was not significantly affected by altitudes. Tourism trampling substantially increased the soil net N mineralization rate at 1030 m altitude (51.4%) but significantly reduced it by 43.5% at 1240 m altitude (Figure 1).

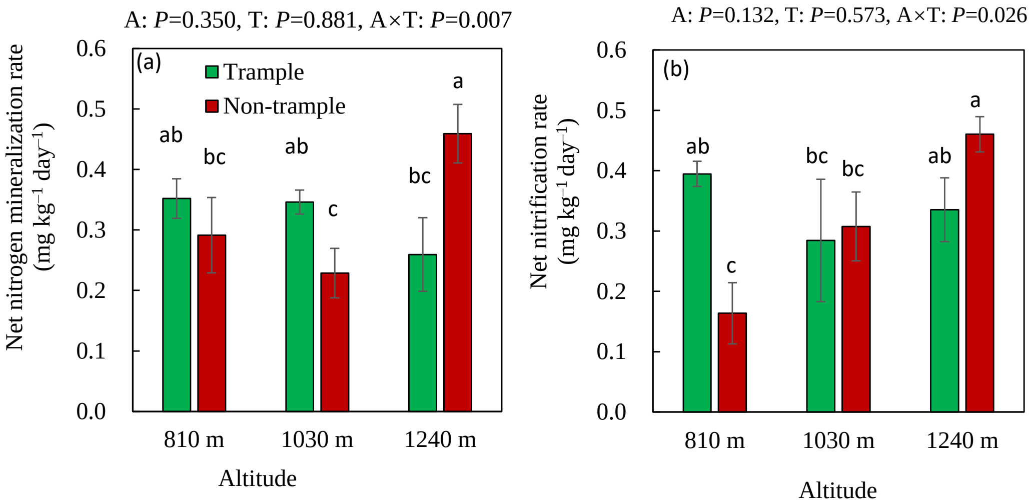

Figure 1. Effects of tourism trampling on soil N mineralization (**a**) and nitrification rate (**b**). Interactive effects of altitude (A) and trample treatment (T) on values based on Two-way ANOVA were shown on the chart. Different lowercase letters indicate significant differences among means at the 0.05 level.

The net N nitrification rate of the non-trampled soil showed an increasing trend with the elevated altitudes, with significantly higher values at 1240 m altitudek (0.460 mg·kg^{-1}·day^{-1}) than that at 810 m and 1030 m altitude ($p < 0.05$, Figure 1). Tourism trampling resulted in a significant increase in the soil net N nitrification rate (141.0%) at an altitude of 810 m but led to a marginal decrease in soil net N nitrification rate (−27.2%) at 1240 m altitude ($p < 0.10$, Figure 1).

3.3. Effects of Variables on Soil Net N Mineralization and Nitrification Rate

According to the simple linear regression analysis, both the soil net N mineralization and nitrification rate exhibited parabolic relationships with soil pH value. The soil N mineralization rate increased significantly with the elevated soil pH value first, reaching the maximum N mineralization rate of 0.386 mg·kg^{-1}·day^{-1} when the pH value reached 4.27, and then gradually decreased with the increased pH value (Figure 2). The soil nitrification rate reached its peak value when soil pH value was 4.31, and then gradually reduced. In contrast, both soil N mineralization and nitrification rates showed inverted parabolic relationships with soil bulk density, reaching the lowest value of 0.263 mg·kg^{-1}·day^{-1} for mineralization rate when the soil bulk density was 1.11 g cm^{-3} (Figure 2). Similarly, the soil nitrification rate reached the lowest value (0.266 mg·kg^{-1}·day^{-1}) when the soil bulk density was 1.09 g cm^{-3}. In addition, soil N mineralization and nitrification rates were significantly positively correlated with soil microbial biomass ($p < 0.05$, Figure 2).

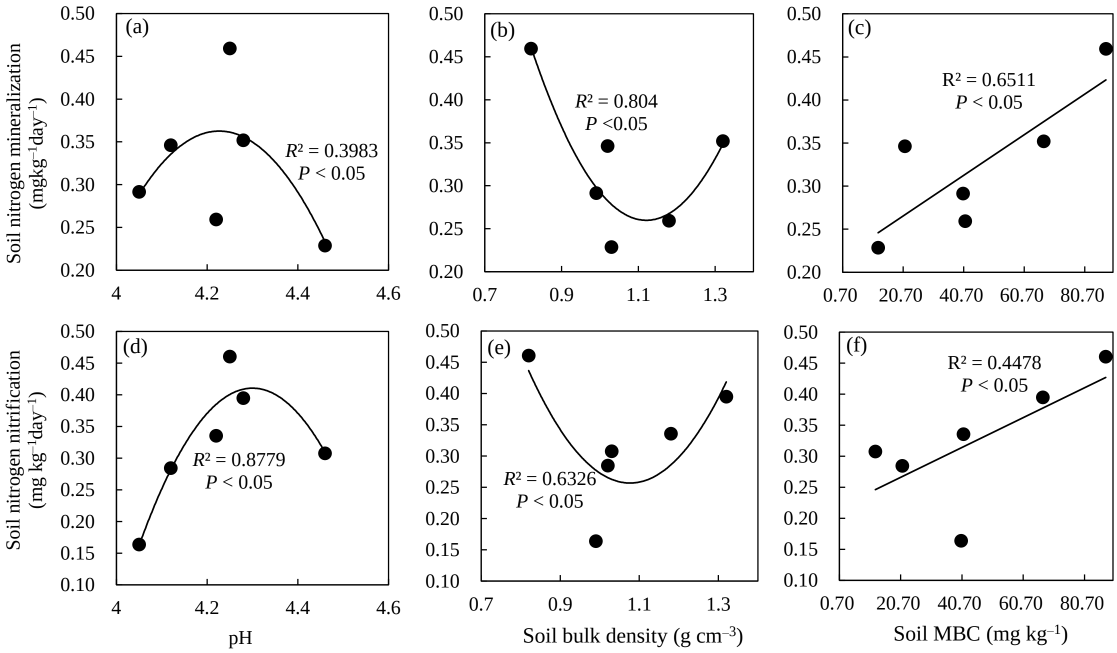

Figure 2. Effects of soil pH value (**a**,**d**), soil bulk density (**b**,**e**), and soil MBC (**c**,**f**) on soil N mineralization and N nitrification.

The effects of different environmental factors on soil N net mineralization were further studied using multiple stepwise regression analysis. It was found that soil MBC and soil bulk density could explain the 74.5% and 15.5% variations in the soil N mineralization rate, respectively. The soil N net nitrification rate was mainly attributed to soil MBC and soil pH value, which together explain 88.2% of the variation (Table 3).

Table 3. Results of multiple stepwise regression on the relationships between soil N mineralization and N nitrification and soil environmental factors.

Factors	Partial R^2	Model Adjusted R^2	F	p
Soil N mineralization				
Soil microbial biomass carbon	0.745	0.745	15.638	0.017
Soil bulk density	0.155	0.900	23.463	0.015
Soil N nitrification rate				
Soil microbial biomass carbon	0.459	0.459	5.24	0.084
pH	0.423	0.882	19.66	0.019

4. Discussion

4.1. Differences in Soil N Mineralization Rates between Altitudes

Our finding that the soil NO_3^--N contents before and after the incubation increased with the elevated altitude was consistent with the results by Zhuang et al. (2008) [24] and Hu et al. (2015) [25]. Soil NH_4^+-N content before incubation showed no significant differences between altitudes, whereas it exhibited a decreased trend with the elevated altitudes after incubation. Inconsistent with our finding, Hu et al. (2015) found that the NH_4^+-N content increased significantly with the elevated altitude on the Emei Mountain [25].

The increased NO_3^--N content with elevated altitude can be attributed to the differences in soil organic matter and microbial activity between altitudes. Firstly, the disturbance intensity of humans or tourism on forest vegetation and soil gradually decreased with the increased altitudes in the Baotianman scenic spot; thus, the species diversity and community productivity tended to increase along the altitude gradient [26]. Therefore, both the quantity and quality of organic matter input from plants to the soil at high altitudes was higher than that at low altitudes, providing more substrates for N transformation [27]. Secondly, plant diversity is usually positively correlated with soil microbial diversity [28]; thus, higher microbial species and abundance could be expected for forest soils at high altitudes. The phenomenon that NH_4^+-N content in cultivated soils reduced with the enhanced altitude may be related to the characteristics of soil NH_4^+-N. Compared with NO_3^--N content, soil NH_4^+-N is easier to be absorbed and utilized by plants [5]. At high altitudes, plant communities have a higher demand for NH_4^+-N in soil due to the higher abundance, which is conducive to the transfer of soil NH_4^+-N. Therefore, the content of NH_4^+-N in soils located at high altitude should be less than that at low altitude.

The soil N mineralization rate at 1030 m altitude was lower than that at 810 m, whereas the value at 1240 m was significantly higher than that at 810 m and 1030 m altitude, which directly led to the inconsistent pattern of the N mineralization rate along the altitude gradient. This finding partly supported our first hypothesis. The relatively low soil N mineralization rate at 810 m altitude could be attributed to the following two aspects. Firstly, the pH value of soil at 1030 m and 810 m altitude was significantly lower than that at 1240 m (Table 1), and the acidic soil may have inhibited the mineralization rate of the soil [16]. Secondly, compared with other well-known mountains in China, the highest altitude of the Baotianman is only 1800 m. Soil moisture at 810 m is lower than that at 1240 m, resulting from the higher air temperature and evaporation rate at low altitude; thus, the lower soil moisture can also inhibit the soil N mineralization rate. However, the soil N nitrification rate increased significantly with the elevated altitude (Figure 1), which is consistent with the results by Hu et al. (2015) [25].

4.2. Effect of Trampling on Soil N Mineralization Rate

Compared with the non-trampled soils, trampled soil had a lower NO_3^--N content, which was consistent with the results under the trampled simulation experiment in the grassland ecosystem conducted by Hou et al. (2003) [29]. However, Chai et al. (2019) found that simulated trampling significantly increased the content of soil available N and the mineralization rate of soil N [18]. The different responses may be related to the variations in the ecosystem and climate types. On the one hand, tourism trampling led to a significant increase in soil bulk density and a decrease in aeration, which in turn resulted in a decrease in the number and activity of soil fauna and microorganisms [7]. On the other hand, the bare land formed by tourist trampling was rarely covered by litter; thus, the litter input and supplement to soil organic matter were very limited [18]. The organic N compounds in soil organic matter are the main source of soil inorganic N [30]. Therefore, shortage in litter input is also an important reason for the low content of soil nitrate N in trample plots. However, the effects of trampling on soil NH_4^+-N content were not significant at all altitudes, which may be ascribed to the relatively stable soil NH_4^+-N itself, which is not easy to lose.

A meta-analysis on the relationships between grazing-induced trampling and the soil N mineralization rate found that grazing led to a significant increase in the soil N mineralization (30.6%) and nitrification rate (12.9%) [31]. In this study, however, we found that tourist trampling reduced the differences in soil N mineralization and nitrification rates between different altitudes, resulting in a trend of convergence. Significant differences between altitudes were found on the effects of tourism trampling on the soil net N mineralization and the N nitrification rate. At 810 m and 1030 m, trampling showed a positive effect on the soil net N mineralization rate; however, trampling resulted in a decrease in the soil net N mineralization rate at 1240 m altitude. The trampling-induced increases in net N mineralization at 810 and 1030 m altitudes could be attributed to the enhanced inorganic N content of soil retrieved after 30 days of field incubation (Table 2). Tourist trampling could directly harden soil and increase soil bulk density. For one thing, to some extent, the setup of PVC tubes for in situ incubation could improve the physical structure and permeability of the compacted soil caused by tourist trampling, which may be favored for the activity of microorganisms related to N turnover in the soil (Figure 2). For another thing, compared with the non-trampled soils, tourist trampling always led to a relatively low soil water content, thus benefiting the maintenance and storage of mineralized inorganic N. The significant differences between the trampled and non-trampled soil at 630 m could be attributed to the substantial increase in soil inorganic N in non-trampled soil after incubation because the value under trampled soil showed no differences between altitudes. As mentioned above, the relatively high species diversity and community biomass at high altitude led to greater soil organic N sources, providing more substrate for the transformation of inorganic N.

5. Conclusions

As one of the major human disturbance factors in forests, tourism trampling is commonly occurring in scenic spots, especially those characterized by natural landscapes, and it is also a critical factor affecting the nutrient cycle of the ecosystem. Based on the comparative study of soil N mineralization in *Quercus variabilis* forests located at different altitudes, we found that tourism trampling led to a significant decrease in soil NO_3^--N content across all altitudes but only led to a significant decrease in soil NH_4^+-N content at low altitudes (810 m). In addition, tourism trampling resulted in a significant reduction in soil N mineralization and nitrification rates only at high altitudes, whereas it promoted soil N mineralization and nitrification rates at low altitudes. Soil microbial activity (MBC) is the key environmental factor regulating the change in soil N mineralization and nitrification rate on Funiu Mountain.

Author Contributions: Conceptualization, Y.L.; methodology, Q.S.; software, Q.S.; validation, Y.L. and Q.S.; formal Analysis, Q.S.; investigation, Y.L. and Q.S.; resources, Q.S.; data curation, Y.L.; writing—original draft preparation, Q.S.; writing—review and editing, Y.L. and Q.L.; visualization, Y.L.; supervision, Y.L.; project administration, Y.L.; funding acquisition, Y.L. All authors have read and agreed to the published version of the manuscript.

Funding: The research was funded by the National Natural Science Foundation of China (31971454 and 31930078) and the Project of Science and Technology of Henan Province (222102320437).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments: We would like to thank the Baotianman Forest Ecosystem Research Station for access to experimental sites.

Conflicts of Interest: The authors declared no conflict of interest.

References

1. Schimel, J.P.; Bennett, J. Nitrogen mineralization: Challenges of a changing paradigm. *Ecology* **2004**, *85*, 591–602. [CrossRef]
2. Koch, O.; Tscherko, D.; Kandeler, E. Temperature sensitivity of microbial respiration, nitrogen mineralization, and potential soil enzyme activities in organic alpine soils. *Glob. Biogeochem. Cycles* **2007**, *21*, GB4017. [CrossRef]
3. Gilliam, F.S.; Lyttle, N.L.; Thomas, A.; Adams, M.B. Soil variability along a nitrogen mineralization and nitrification gradient in a nitrogen-saturated hardwood forest. *Soil Sci. Soc. Am. J.* **2005**, *69*, 247–256. [CrossRef]
4. Smit, A.; Velthof, G.L. Comparison of indices for the prediction of nitrogen mineralization after destruction of managed grassland. *Plant Soil* **2010**, *331*, 139–150. [CrossRef]
5. Constantinides, M.; Fownes, J.H. Nitrogen mineralization from leaves and litter of tropical plants: Relationship to nitrogen, lignin and soluble polyphenol concentrations. *Soil Biol. Biochem.* **1994**, *26*, 49–55. [CrossRef]

6. Chen, Z.; Li, Y.; Chang, S.X.; Xu, Q.; Cai, Y. Linking enhanced soil nitrogen mineralization to increased fungal decomposition capacity with Moso bamboo invasion of broadleaf forests. *Sci. Total Environ.* **2021**, *771*, 144779. [CrossRef]
7. Chu, H.; Grogan, P. Soil microbial biomass, nutrient availability and nitrogen mineralization potential among vegetation-types in a low arctic tundra landscape. *Plant Soil* **2009**, *329*, 411–420. [CrossRef]
8. Buzin, I.S.; Makarov, M.I.; Malysheva, T.I.; Kadulin, M.S.; Koroleva, N.E.; Maslov, M.N. Transformation of nitrogen compounds in soils of mountain tundra ecosystems in the Khibiny. *Eurasian Soil Sci.* **2019**, *52*, 518–525. [CrossRef]
9. Schrama, M.; Heijning, P.; Bakker, J.P.; van Wijnen, H.J.; Berg, M.P.; Olff, H. Herbivore trampling as an alternative pathway for explaining differences in nitrogen mineralization in moist grasslands. *Oecologia* **2013**, *172*, 231–243. [CrossRef]
10. Turner, M.M.; Henry, H.A. Net nitrogen mineralization and leaching in response to warming and nitrogen deposition in a temperate old field: The importance of winter temperature. *Oecologia* **2010**, *162*, 227–236. [CrossRef]
11. Liu, Y.; Liu, X.; Yang, Z.; Li, G.; Liu, S. Wild boar grubbing causes organic carbon loss from both top-and sub-soil in an oak forest in central China. *For. Ecol. Manag.* **2020**, *464*, 118059. [CrossRef]
12. Chabala, L.M.; Angombe, S.; Amelung, W.; Lark, R.M. The effect of water deficit and livestock stocking density on soil organic carbon stocks in Namibia. *Geoderma* **2022**, *407*, 115522. [CrossRef]
13. Kissling, M.; Hegetschweiler, K.T.; Rusterholz, H.-P.; Baur, B. Short-term and long-term effects of human trampling on above-ground vegetation, soil density, soil organic matter and soil microbial processes in suburban beech forests. *Appl. Soil Ecol.* **2009**, *42*, 303–314. [CrossRef]
14. Li, Q.; Dai, M.; Luo, F. Influence of tourism disturbance on soil microbial community structure in Dawei Mountain national forest park. *Sustainability* **2022**, *14*, 1162. [CrossRef]
15. Yan, R.; Yang, G.; Chen, B.; Wang, X.; Yan, Y.; Xin, X.; Li, L.; Zhu, X.; Bai, K.; Rong, Y.; et al. Effects of livestock grazing on soil nitrogen mineralization on Hulunber meadow steppe, China. *Plant Soil Environ.* **2016**, *62*, 202–209. [CrossRef]
16. Wang, X.; Guo, X.; Zheng, R.; Wang, S.; Liu, S.; Tian, W. Effects of grazing on nitrogen transformation in swamp meadow wetland soils in Napahai of Northwest Yunnan. *Acta Ecol. Sin.* **2018**, *38*, 2308–2314.
17. Ramirez, J.I.; Jansen, P.A.; den Ouden, J.; Moktan, L.; Herdoiza, N.; Poorter, L. Above- and below-ground cascading effects of wild ungulates in temperate forests. *Ecosystems* **2021**, *24*, 153–167. [CrossRef]
18. Chai, J.; Xu, C.; Zhang, D.; Xiao, H.; Pan, T.; Yu, X. Effects of simulated trampling and rainfall on soil nutrients and enzyme activity in an alpine meadow. *Acta Ecol. Sin.* **2019**, *39*, 333–344.
19. Guo, Y.; Wang, P. Studies on effect of recreational activities on soil fertility and soil enzyme. *J. Soil Sci.* **2009**, *40*, 529–532.
20. Liu, Y.; Shang, Q.; Wang, L.; Liu, S. Effects of understory shrub biomass on variation of soil respiration in a temperate-subtropical transitional oak forest. *Forests* **2019**, *10*, 88. [CrossRef]
21. Nelson, D.W.; Sommers, L.E.; Sparks, D.; Page, A.; Helmke, P.; Loeppert, R.; Soltanpour, P.; Tabatabai, M.; Johnston, C.; Sumner, M. Total carbon, organic carbon, and organic matter. In *Methods of Soil Analysis: Part 3 Chemical Methods*; Soil Science Society of America: Madison, WI, USA, 1996; pp. 961–1010.
22. Vance, E.; Brookes, P.; Jenkinson, D. An extraction method for measuring soil microbial biomass C. *Soil Biol. Biochem.* **1987**, *19*, 703–707. [CrossRef]
23. Liu, Y.; Liu, S.; Miao, R.; Liu, Y.; Wang, D.; Zhao, C. Seasonal variations in the response of soil CO_2 efflux to precipitation pulse under mild drought in a temperate oak (Quercus variabilis) forest. *Agric. For. Meteorol.* **2019**, *271*, 240–250. [CrossRef]
24. Zhuang, S.; Liu, G.; Xu, M.; Wang, M. Nitrogen mineralization in forest soils varying in elevation. *Acta Pedol. Sin.* **2008**, *45*, 1194–1198.
25. Hu, X.; Yi, N.; Cai, S.; Yin, P.; Liu, H. The soil nitrogen cycle of different elevation in Mt. Emei. *J. Jian Univ. Nat. (Sci. Med. Ed.)* **2015**, *36*, 378–382.
26. Zhang, Y.; Zhang, X.; Feng, W.; Liu, Y.; Zhou, Y. Plant species diversity of deciduous broad-leaved forest and needle and broad-leaved mixed forest in Jigong Mountain, China. *J. Yunnan Agric. Univ.* **2014**, *29*, 799–805.
27. Yang, Y.; Zhang, L.; Wei, X.; Chen, Y.; Yang, W.; Tan, B.; Yue, K.; Ni, X.; Wu, F. Litter removal reduced soil nitrogen mineralization in repeated freeze-thaw cycles. *Sci. Rep.* **2019**, *9*, 2052. [CrossRef]
28. Loranger-Merciris, G.; Barthes, L.; Gastine, A.; Leadley, P. Rapid effects of plant species diversity and identity on soil microbial communities in experimental grassland ecosystems. *Soil Biol. Biochem.* **2006**, *38*, 2336–2343. [CrossRef]
29. Hou, F.; Ren, J. Evaluation on trampling of grazed Gansu wapiti (Cervus elaphus kansuensis Pocock) and its effects on soil property in winter grazing land. *Acta Ecol. Sin.* **2003**, *23*, 486–495.
30. Elrys, A.S.; Ali, A.; Zhang, H.; Cheng, Y.; Zhang, J.; Cai, Z.C.; Muller, C.; Chang, S.X. Patterns and drivers of global gross nitrogen mineralization in soils. *Glob. Change Biol.* **2021**, *27*, 5950–5962. [CrossRef]
31. Zhou, G. *Effect of Grazing on Carbon and Nitrogen Cycles in Grassland Ecosystem: A Meta-Analysis*; Jiangsu University: Zhenjiang, China, 2016.