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Article

Effects of litter decomposition on soil N in *Picea mongolica* forest at different forest ages

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Abstract: The seasonal and vertical spatial variation characteristics of total N, NH_4^+—N and NO_3^-—N in *Picea mongolica* forest soil were studied for different stand ages. Results showed that: (1) NH_4^+—N in the soil was positively correlated with sample date, soil NO_3^-—N, and forest age ($p<0.05$), and negatively correlated with soil depth ($p<0.01$). NO_3^-—N in the soil was negatively correlated with sample date and forest age ($p<0.05$), and significantly negatively correlated with soil depth ($p<0.01$). (2) the NH_4^+—N content is greater than that of NO_3^-—N in each soil layer for the three forest ages. The correlation analysis indicated which factors influenced NH_4^+—N and NO_3^-—N in the soil. The content decreased during February and November, and increased in May and August. (3) The total N, NH_4^+—N, and NO_3^-—N in the forest soils across the three forest ages increased with the depth of the soil layer (0–50 cm), and showed an overall downward trend. The contents of NH_4^+—N in the soil layer from the young forest (0–10 cm, 10–20 cm and 20–30 cm, 30–40 cm, and 40–50 cm) differed significantly ($p<0.05$), as did the NO_3^-—N results ($p<0.05$), while results from the middle-aged forest and near-mature forest increased with soil layer depth. There was no significant difference in the NH_4^+—N soil content. (4) The NH_4^+—N in the forest soils showed a trend from mature forest > middle-aged forest > young forest. This trend for soil NO_3^-—N content is consistent with that of the NH_4^+—N content in the *Picea mongolica* forest soil.

Keywords: Horqin sandy land; *Picea mongolica* forest; NH_4^+–N; NO_3^-—N; Seasonal dynamics

1. Introduction

N is a major macronutrient necessary for plant growth and development, as well as the main limiting factor for forest ecosystem productivity [1,2]. NH_4^+—N and NO_3^-—N are available N that can be directly absorbed and utilized by plants. Changes in their content in the soil directly affect the migration and transformation of soil N and plant productivity [3]. The N, NH_4^+—N, and NO_3^-—N contents in the soil of different forest types and surfaces have been found to differ significantly. Many studies have been undertaken on the chemometric characteristics of soil N in forest ecosystems in China and other countries. These include different forest ages [4,5], land use modes [6,7], succession stages [8] altitudes [9,10], tree species [11,12], and more. In recent years, several studies have been conducted on different tree species, as different species have different habitats with different soil physical and chemical properties, soil nutrient composition and distribution within the ecosystem [13,14]. However, few studies have been conducted in the *Picea mongolica* forest at the North China forest ecotone. Therefore, it is of great significance to study the characteristics of seasonal variation in soil N in this forest.

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Picea mongolica is a tree species native to the northern agropastoral ecotone. This species mainly grows on sunny slopes in the mountains at an altitude of 1300–1500 m. To date, few studies have been conducted on the quantitative characteristics of soil N in this ecosystem with a focus on forest age, soil depth, and seasonality. In this study, analyses of variations in forest age, soil depth, and seasonal dynamic changes are combined. We compared and analyzed seasonal dynamic changes in soils at different levels of *Picea mongolica* forest and examined the migration and transformation tendency for total and available N to provide a scientific basis for the management of the *Picea mongolica* forests. The results from this study can provide a reference for use in the management and cultivation of artificial forests.

2. Materials and Methods

2.1. Site description

The study area is located in the Baiyin Oboo Nature Reserve (43°30'–43°36'N, 117°03'–117°16'E) in Keshketeng county on the eastern edge of Hunshandak Sandy Land, with an area of approximately 1947 km^2. The region has a temperate grassland climate, with an average annual temperature of -1.4 °C, an average temperature of -23.4 °C in January, and 17.4 °C in July. The average annual frost-free period is 78 days, with an annual precipitation of 360–440 mm, an average annual evaporation of 1035.6 mm, and an altitude of 1300–1500 m. The soil type is gray forest soil, and the flora belongs to the plant distribution area of Mongolia. In terms of plant species composition, common taxa that are present include *Larix decidua* Mill., *Juniperus sabina* var. *davurica* (Pallas) Farjon, *Spiraea aquilegifolia, S. dahurica* (Rupr.) Maxim., and *Pinus tabuliformis* Carr.

2.2. Sample plot setting and sample collection

Three forest areas with young, middle-aged, and near-mature *Picea mongolica* forest were selected in the Baiyinaobao National Nature Reserve. In each forest stand, three 10 x 10 m sampling plots that were in full sun, uniformly distributed, and with good vegetation growth were selected. Five sampling points were chosen in an "s" shape within each sample plot. During March, May, July, September, and January 2017, soil samples were collected from five different soil levels, namely 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, and 40–50 cm from the three forest types for indoor treatment and analysis.

Table 1. Key vegetation parameters of the sampling plots. The data presented here were collected during March 2017. Values presented are the mean±standard error. Soil sample numbers were similar to 15.

forest type				Soil layer (0–30 cm)		
Age of stand (a)	Elevation gradient m	Average DBH/ cm	Average height m	Soil pH	Soil moisture/ %	Soil temperature ℃
young forest（0～5a）	1344	1.79±2.15	2.06±0.71	7.01±0.12	35.95±0.45	-15.78±2.49
middle-aged forest（5～30a）	1352	8.03±4.81	8.15±1.86	6.67±0.03	42.45±4.13	-14.59±2.61
near-mature forest（30～40a）	1342	14.26±4.12	13.94±2.15	6.69±0.01	17.28±2.61	-15.33±2.42

Table 2. Mean air temperature and precipitation in different months.

Months	Mean air temperature (°C)	Mean precipitation (mm)
February 2017	-14.61	0.30
May 2017	14.50	13.3
August 2017	13.16	0.65
November 2017	-13.79	0

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Following air drying of the samples indoors, impurity removal, and grinding through a 100-mesh screen, the soil total N, NH_4^+—N, and NO_3^-—N were determined. N was determined using H_2SO_4-H_2O_2 digestion indophenol blue colorimetry [15]. NH_4^+—N was determined using indophenol blue colorimetry [15]. NO_3^-—N was determined using phenol disulfonic acid colorimetry in China National Standard (determination of NO_3^-—N in the forest soils) (ly / y1233-1999).

2.3. Statistical analysis

Excel 2017 and SPSS 22.0 software were used for statistical analysis of data. One-way analysis of variance (ANOVA) and least significant difference (LSD) were used for analysis of variance and multiple comparisons (α = 0.05). The Pearson method was used for correlation analysis. Amos 22.0 software was used to establish a structural equation model. The data in Table 3 is the mean±standard deviation.

3. Results and analysis

3.1. Seasonal variation of soil total N content with soil depth and stand age

Table 3. Soil ammonium nitrogen and nitrate nitrogen contents and their vertical distribution in different stand ages and times in young forest (Y-F); middle-aged forest (M-F); and near-mature forest (N-F). Different lowercase letters in the same column denote significant differences between soil layers. Different capital letters in the same row denote significant differences across altitudes at the 0.05 level.

times	Soil layer (cm)	Total N (mg·kg^{-1})			NNH_4N (mg·kg^{-1})			NNO_3N (mg·kg^{-1})		
		Y-F	M-F	N-F	Y-F	M-F	N-F	Y-F	M-F	N-F
March 2017.	0-10	37.007±1.43	22.733±0.66	26.88±0.23	0.262±0.16	0.112±0.14	0.084±0.02	21.937±11.75	24.028±10.39	25.198±3.29
	10--20	14.917±0.64	13.817±0.29	30.249±0.47	0.133±0.06	0.073±0.04	0.032±0.03	12.81±3.01	11.871±1.63	15.473±10.85
	20--30	12.9±0.52	10.457±0.83	10.377±0.55	0.064±0.02	0.034±0.02	0.029±0.03	9.409±0.58	8.9±0.56	9.98±1.80
	30--40	12.517±0.81	15.96±0.00	12.963±0.06	0.044±0.01	0.028±0.00	0.026±0.00	8.686±0.54	12.862±1.54	9.89±1.12
	40--50	12.023±0.41	12.55±0.00	11.133±0.64	0.038±0.01	0.045±0.03	0.019±0.01	10.373±1.08	10.25±1.33	10.611±3.04
May2017.	0--10	59.95±1.21	30.317±1.44	25.191±0.76	0.182±0.21	0.09±0.04	0.111±0.09	33.572±14.81	22.587±6.16	36.094±12.77
	10--20	62.417±0.64	33.033±1.11	41.75±1.21	0.059±0.01	0.059±0.03	0.133±0.17	38.116±16.38	34.473±15.62	42.668±24.25
	20--30	22.917±1.01	43.367±1.96	27.423±0.92	0.085±0.08	0.112±0.12	0.02±0.01	21.005±1.64	36.094±9.98	40.236±15.46
	30--40	21.227±1.25	21.751±0.35	23.967±0.62	0.126±0.13	0.021±0.02	0.015±0.01	22.466±2.84	30.601±18.72	31.862±14.58
	40--50	23.25±0.87	26.083±1.67	25.323±0.98	0.068±0.05	0.018±0.01	0.017±0.01	20.054±0.54	21.957±2.85	24.118±1.77
July 2017.	0--10	59.55±0.52	31.417±0.46	25.787±0.27	0.061±0.00	0.124±0.00	0.735±0.00	54.385±0.00	31.251±0.00	22.416±0.00
	10--20	62.45±0.69	33.342±0.58	41.163±0.20	0.057±0.00	0.074±0.00	0.057±0.00	59.95±0.00	33.412±0.00	36.194±0.00
	20--30	23.817±0.55	44.433±0.12	26.99±0.17	0.192±0.00	0.332±0.00	0.033±0.00	21.15±0.00	42.597±0.00	23.497±0.00
	30--40	22.15±0.35	21.573±0.04	24.6±0.48	0.306±0.00	0.033±0.00	0.033±0.00	20.55±0.00	21.192±0.00	22.307±0.00
	40--50	23.903±0.27	27.283±0.40	25.603±0.50	0.153±0.00	0.032±0.00	0.025±0.00	19.988±0.00	20.658±0.00	21.497±0.00
September 2017.09	0--10	23.75±0.35	51.03±0.52	38.513±0.28	0.012±0.02	0.083±0.08	0.061±0.07	25.968±5.34	42.308±16.01	27.9±8.46
	10--20	27.133±0.65	63.61±0.00	47.607±0.30	0.019±0.03	0.024±0.02	0.079±0.06	33.048±9.34	39.156±17.72	37.715±12.24
	20--30	25.06±0.10	50.955±0.00	54.35±0.13	0.03±0.04	0.111±0.08	0.058±0.04	22.916±1.90	36.995±12.81	38.525±18.15
	30--40	41.257±0.15	34.385±0.00	25.35±0.29	0.017±0.03	0.035±0.03	0.067±0.11	31.853±7.71	31.592±8.13	33.123±8.73
	40--50	31.131±0.11	33.139±0.00	25.425±0.05	0.037±0.05	0.065±0.02	0.036±0.06	33.078±3.51	34.203±6.24	24.838±9.97
November 2017	0--10	30.755±0.56	12.908±0.22	21.34±0.42	0.049±0.01	0.025±0.04	0.103±0.07	17.253±10.92	20.696±9.41	26.819±5.85
	10--20	17.083±0.30	22.359±0.37	28.003±0.29	0.042±0.00	0.047±0.02	0.093±0.04	9.616±4.24	15.113±4.80	35.734±9.73
	20--30	14.137±0.15	21.052±0.17	13.943±0.36	0.018±0.01	0.046±0.01	0.104±0.06	11.902±1.79	14.548±5.40	11.241±1.95
	30--40	29.39±0.54	11.073±0.24	9.68±0.32	0.031±0.02	0.053±0.03	0.099±0.02	16.791±10.23	11.511±6.26	13.312±4.25
	40--50	23.84±0.33	11.227±0.28	17.132±0.26	0.026±0.01	0.033±0.01	0.071±0.04	15.591±5.06	12.321±1.65	27.179±25.29

During March and November 2017, the total N content of the soils from *Picea mongolica* forest stands across the three age groups showed a downward trend with increasing soil depth (Table 3). There were significant differences in the total N content between 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, and 40–50 cm soil layers ($p < 0.05$). During March 2017, the maximum values of the total N across the three stand ages (37.007±0.43 mg/kg,

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22.733±0.06 mg/kg, and 26.88±0.23 mg/kg) were recorded from the 0–20 cm soil layer. The minimum values (12.023±0.41 mg/kg, 10.457±0.83 mg/kg, 10.377± 0.55 mg/kg) were recorded from the 30–50 cm soil layer. The average soil total N contents recorded in near-mature, young, and middle-aged forests were 18.32 mg/kg, 17.87 mg/kg, and 15.96 mg/kg, respectively. During November 2017, the maximum value of the total N for the three forest ages (30.755±0.56 mg/kg, 22.359±0.37 mg/kg, and 28.003±0.29 mg/kg) was recorded from the 0–20 cm soil layer and the minimum value was recorded in the 30–50 cm soil layer. The average soil total N contents recorded in young, near-mature, and middle-aged forests in this period were 23.04 mg/kg, 18.01 mg/kg, and 15.72 mg/kg, respectively.

By recording the year, soil depth, forest type, pH value, soil temperature, soil humidity, soil organic matter, litter N content, litter carbon content, and litter C/N content as independent variables, a linear regression fitting model for all n was constructed. From the linear fitting results in Table 4, Figure 1, and Figure 2, there was a good linear fit for the model with a significant p value of 0.001. The results are shown in Table 3. The total N content across the three forest ages from May, July, and September 2017 first increased and then decreased with increasing soil depth. There was a significant difference in the total N content between 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, and 40–50 cm ($p < 0.05$), during May 2017. The maximum age total N contents for young and near-mature forests (62.417±0.64 mg/kg and 41.75±1.21 mg/kg, respectively) were recorded from the 10–20 cm soil layer. The maximum age total N content from the middle-aged forest was recorded from the 20–30 cm soil layer (43.367±1.96 mg/kg). The minimum forest age was recorded from the 30–50 cm soil layer. The average soil total N contents in the young, middle-aged, and near-mature forests were 37.95 mg/kg, 30.961 mg/kg, and 28.73 mg/kg, respectively. In July, the maximum value of total N in young and near-mature forests (62.45±0.69 mg/kg and 41.16±0.2 mg/kg, respectively) was recorded from the 10–20 cm soil layer. The maximum total N content from the middle-aged forests was recorded from the 20–30 cm soil layer (44.43±0.12 mg/kg). The minimum age for all three forest age groups was recorded from the 30–50 cm soil layer. The average soil total N contents in the young, middle-aged, and near-mature forests were 38.37 mg/kg, 31.61 mg/kg, and 28.82 mg/kg, respectively. In September, the maximum values of total N from the young and the middle-aged forests (41.25±0.15 mg/kg and 63.61±0.01 mg/kg, respectively) were recorded from the 10–20 cm soil layer. The maximum value of total N from the near-mature forest was recorded from the 20–30 cm soil layer (54.35±0.13 mg/kg). The minimum age across the three forest age groups was recorded in the 30–50 cm soil layer. The average soil total N content recorded in the middle-aged, near-mature, and young forests were 46.62 mg/kg, 38.24 mg/kg, and 29.66 mg/kg. In 2017, the total N content across the three forest age groups first increased and then decreased over time. In May and July, the highest total N content was recorded across all three forest age groups.

Table 4. Linear fitting table for soil total nitrogen in *Picea mongolica* forest (F-test). The dependent variable was total N.

Model		Sum of squares	Freedom	Mean square	F	significance
1	regression	632256641	10	63225664	2.319	0.013b
	residual	7062498135	259	27268333		
	total	7694754776	269			

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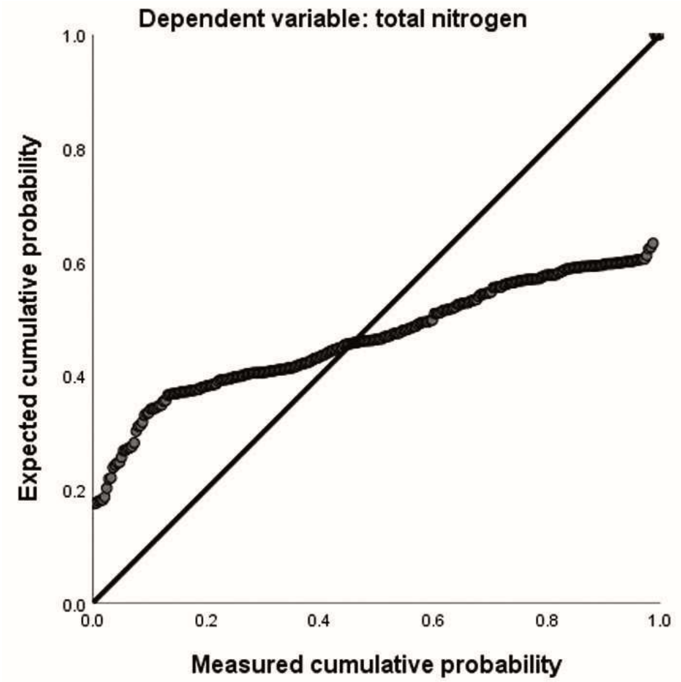

Figure 1. Normal P-P diagram showing regression standardized residuals.

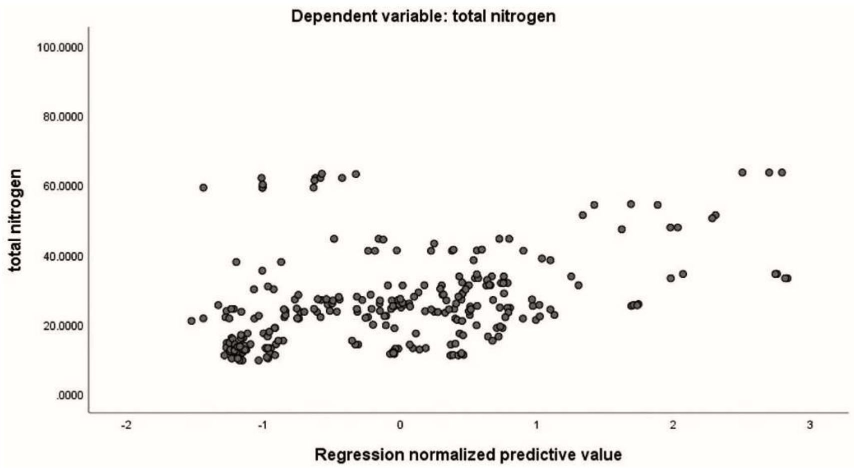

Figure 2. Scatter plot showing total nitrogen.

By recording the year, soil depth, forest type, pH value, soil temperature, soil humidity, soil organic matter, litter N content, litter carbon content, and litter C/N content as independent variables, the linear regression fitting model for all n was constructed. From the linear fitting results in Table 4, Figure 1, and Figure 2, the overall trend of P-P on the linear fitting graph has high linear coverage and normal distribution of the regression value with a significant *p-value* of 0.001. The results are shown in Table 5.

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Table 5. Multivariate analysis of variance of soil total nitrogen of *Picea mongolica* forest (T-test).

model	Nonstandard Coefficient		Standardization coefficient	t	significance
(constant)	52347.16	27613.11		1.90	0.06
Particular year	-3899.58	1154.61	-1.25	-3.38	0.00
Forest type	-1327.88	550.65	-0.20	-2.41	0.02
Soil depth	5.12	24.72	0.01	0.21	0.08
PH value	-118.22	1006.91	-0.01	-0.12	0.19
humidity	-367.86	390.42	-0.11	-0.94	0.35
temperature	-24.02	78.97	-0.05	-0.30	0.76
Litter N content	-3047.91	3006.83	-0.22	-1.01	0.31
Litter N content	255.93	165.93	1.21	1.54	0.12
Litter CN ratio	-1617.78	569.09	-2.82	-2.84	0.01
Soil organic matter content	8.19	6.66	0.09	1.23	0.22

From the linear fitting results in Table 5, humidity, temperature, and CN ratio of litter and organic matter have had a considerable impact on the level of total N, and the highest contribution rate. Although, the impact of litter N content and pH value is slightly lower, the p-values for all the other influencing factors, except for litter N content, were greater than 0.05, indicating significant results.

3.2. Characteristics of seasonal variation of soil NH_4^+—N content with soil depth and stand age

In March and November 2017, the content of NH_4^+—N in soil for the three forest stand ages showed an overall downward trend with increasing soil depth (Table 3). There were significant differences in the NH_4^+—N content in the 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, and the 40–50 cm soil layers (p<0.05). In March 2017, the maximum values of NH_4^+—N across the three forest ages (0.262±0.16 mg/kg, 0.112±0.14 mg/kg, and 0.084±0.02 mg/kg) were recorded from the 0–10 cm soil layer, and the minimum values (0.038±0.01 mg/kg, 0.028±0.01 mg/kg, and 0.019±0.01 mg/kg) were recorded in the 30–50 cm soil layer. The average soil NH_4^+ —N contents recorded for young middle-aged, and near-mature forests were 0.108 mg/kg, 0.068 mg/kg, and 0.038 mg/kg, respectively. In November 2017, the maximum values of NH_4^+—N across the three forest ages (0.049±0.01 mg/kg, 0.053±0.03 mg/kg, and 0.104±0.06 mg/kg, respectively) were recorded from the 0–20 cm soil layer, and the minimum values were recorded from the 30–50 cm soil layer. The average soil NH_4^+—N content recorded from near-mature, middle-aged, and young forests were 0.094 mg/kg, 0.041 mg/kg, and 0.033 mg/kg, respectively. The NH_4^+—N content across the three forest ages in May, July, and September 2017 first increased and then decreased with increasing soil depth. The soil total N contents between the 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, and 40–50 cm soil layers differed significantly (p<0.05). In May 2017, the maximum value of NH_4^+—N for young and near-mature forests (0.182±0.21 mg/kg and 0.133±0.17 mg/kg, respectively) was recorded from the 10–20 cm soil layer. The maximum value of total N (0.112± 0.12 mg/kg) for middle-aged forest was recorded from the 20–30 cm soil layer. The minimum age for the three forest age groups was recorded from the 30-50 cm soil layer. The average soil NH_4^+—N content recorded from young, middle-aged, and near-mature forests were 0.103 mg/kg, 0.060 mg/kg, and 0.059 mg/kg, respectively. In July, the maximum values of NH_4^+—N for young and near-mature forests (0.306±0.01 mg/kg and 0.332±0.01 mg/kg) were recorded from the 10–20 cm soil layer. The maximum value of NH_4^+—N (0.735±0.01 mg/kg) from the middle-aged forest was recorded from the 20–30 cm soil layer. The minimum age for the three forest age groups was recorded from the 30–50 cm soil layer. The average soil NH_4^+—N contents recorded for near-mature, young, and middle-aged forests were 0.176 mg/kg, 0.154 mg/kg, and 0.119 mg/kg, respectively. In September, the maximum values of NH_4^+—N for young and near-mature forests (0.03±0.04 mg/kg and 0.11±0.08 mg/kg) were recorded from the 10–20 cm soil layer. The maximum value of NH_4^+—N (0.079±0.06 mg/kg) from the middle-aged forest was recorded from the 20–30 cm soil layer. The minimum age for the three forest age

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groups was recorded from the 30–50 cm soil layer. The average soil total N contents recorded for middle-aged near-mature, young and forests were 0.063 mg/kg, 0.06 mg/kg, and 0.037 mg/kg, respectively.

Table 6. Linear fitting table for soil ammonium nitrogen in *Picea mongolica* forest (F-test).

Model		Sum of squares	Freedom	Mean square	F	significance
1	regression	0.681	10	0.068	8.488	0.001b
	residual	2.079	259	0.008		
	total	2.761	269			

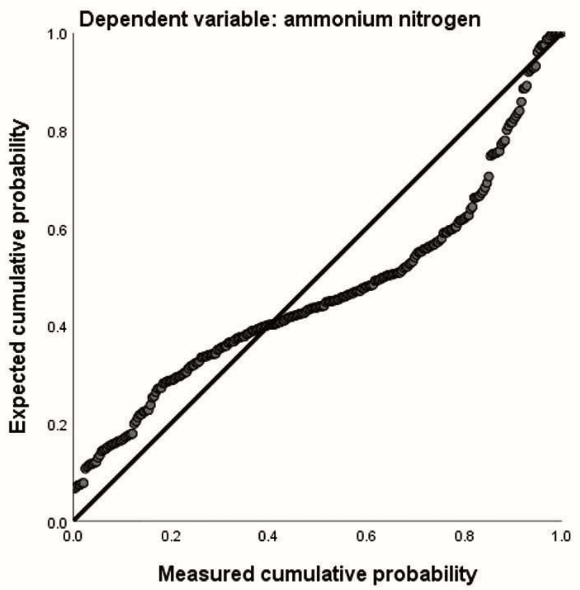

Figure 3. Normal P-P diagram of regression standardized residuals.

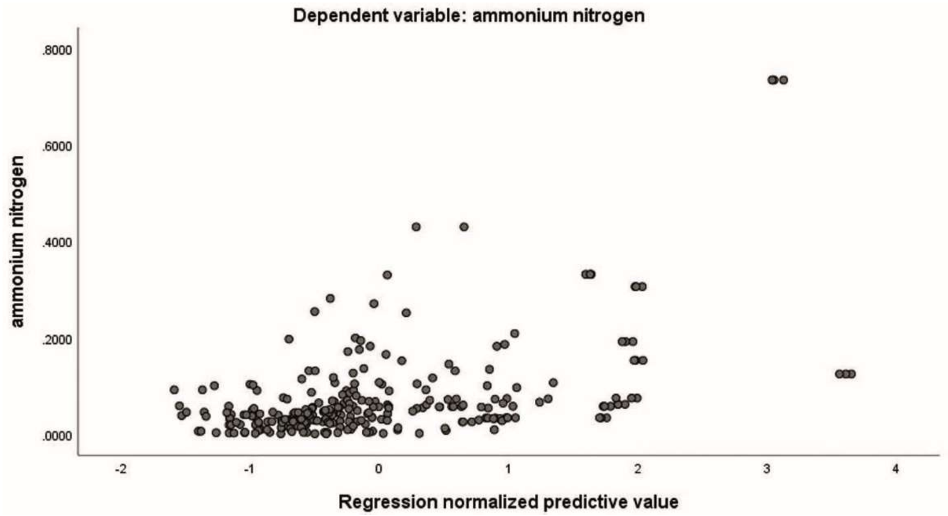

Figure 4. Scatter plot of ammonium-nitrogen prediction.

By recording the year, soil depth, forest type, pH value, soil temperature, soil humidity, soil organic matter, litter N content, litter carbon content, and litter C/N content as independent variables, the linear regression fitting model for all n was constructed. From the linear fitting results in Table 3, Figure 3, and Figure 4, the linear fitting results were

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high, the predicted accumulation probability was similar to the actual accumulation probability, the linear coverage rate was high, and there was a normal distribution for the predicted regression value. There was a significant p-value of 0.001. The results are shown in Table 7.

Table 7. Multivariate analysis of variance of soil ammonium nitrogen in *Picea mongolica* forest (T-Test).

model	Nonstandard Coefficient Beta		Standardized number Beta	t	Significance
particular year	0.04	0.02	0.59	2.75	0.05
Forest type	0.02	0.01	0.12	2.54	0.02
Soil depth	0.00	0.00	-0.11	-2.82	0.07
PH value	0.02	0.02	0.09	1.11	0.27
humidity	0.03	0.01	0.53	4.81	0.00
temperature	0.00	0.00	-0.03	-1.23	0.02
Litter N content	0.01	0.05	0.05	0.25	0.80
Litter N content	-0.01	0.00	-1.65	-2.32	0.02
Litter CN ratio	0.03	0.01	2.39	2.66	0.01
Soil organic matter content	0.00	0.00	0.16	2.33	0.02

The linear fitting results in Table 5, including humidity, temperature, and CN ratio of litter and organic matter have a considerable impact on total N, and the highest contribution rate. The impact of litter N content and pH value is slightly lower, but the p-values for all other influencing factors, with the exception of litter N content are greater than 0.05, indicating a significant result.

3.3. Characteristics in seasonal dynamic variation of soil NO_3^-—N content with soil depth and stand age

During March and November 2017, the soil NO_3^-—N content across the three forest stand ages first decreased and then increased with increasing soil depth (Table 3). There were significant differences in NO_3^-—N content between the 0–10 cm, 10–20 cm and 20–30 cm, 30–40 cm, and 40–50 cm soil layers ($p<0.05$). In March 2017, the maximum values for NO_3^-—N (21.937±11.75 mg/kg, 24.028±10.39 mg/kg, and 25.198±3.29 mg/kg) across the three forest ages were recorded from the 0–10 cm soil layer. The minimum values (8.686±0.54 mg/kg, 8.9±0.56 mg/kg, and 9.89±1.12 mg/kg) were recorded from the 30–40 cm soil layer. The average soil NO_3^-—N contents recorded in the near-mature, middle-aged, and young forests were 14.23 mg/kg, 13.58 mg/kg, and 12.64 mg/kg, respectively. In November 2017, the maximum values of NO_3^-—N across all three forest age groups (17.253±10.92 mg/kg, 20.696±9.41 mg/kg, and 35.734±9.73 mg/kg) were recorded from the 0–20 cm soil layer, and the minimum values were recorded from the 30–50 cm soil layer. The average soil NO_3^-—N contents recorded from the near-mature, middle-aged, and young forests were 22.86 mg/kg, 14.83 mg/kg, and 14.23 mg/kg.

The soil NO_3^-—N content across the three forest ages during May, July, and September 2017 first increased and then decreased with increasing soil depth. There was a significant difference in the total N content between the 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, and 40–50 cm soil layers ($p<0.05$). During May 2017, the maximum values of NO_3^-—N from young and near-mature forests (38.116±16.38 mg/kg and 42.668±24.25 mg/kg, respectively) were recorded from the 10–20 cm soil layer. The maximum value of NO_3^-—N from middle-aged forest was recorded from the 20–30 cm soil layer (36.094±9.98 mg/kg). The minimum age across the three forest age groups was recorded from the 30–50 cm soil layer. The average soil NO_3−N contents recorded from near-mature, middle-aged, and young forests were 34.995 mg/kg, 29.14 mg/kg, and 27.04 mg/kg, respectively. In July, the maximum values of NO_3^-—N from young and near-mature forests (59.95±0.01 mg/kg and 36.194±0.01 mg/kg) were recorded from the 10–20 cm soil layer. The maximum value of NO_3^-—N from the middle-aged forest was recorded from the 20–30 cm soil layer

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(42.597±0.01 mg/kg). The minimum age from the three forest age groups was recorded from 30–50 cm soil layer. The average soil NO_3^-—N content recorded for young, middle-aged, and near-mature forests were 35.20 mg/kg, 29.83 mg/kg, and 25.182 mg/kg, respectively. In September, the maximum values for NO_3^-—N in young and middle-aged forests (33.048±9.34 mg/kg and 42.308±16.01 mg/kg, respectively) were recorded from the 0–20 cm soil layer. The maximum value for NO_3^-—N in near-mature forests (38.523±18.12 mg/kg) was recorded from the 20–30 cm soil layer. The minimum age for the three forest age groups was recorded from the 30–50 cm soil layer. The average soil NO_3^-—N content recorded for middle-aged, near-mature, and young forests were 36.85 mg/kg, 29.37 mg/kg, and 24.83 mg/kg, respectively.

In 2017, the soil NO_3^-—N increased first and then decreased over time. In May and July, the total N content for the three forest age groups was the highest recorded during the study.

Table 8. Linear fitting table for soil nitrate nitrogen in *Picea mongolica* forest (F-test). The dependent variable was nitrate (N).

Model		Sum of squares	Freedom	Mean square	F	significance
1	regression	1348848.91	10	134884.89	2.98	0.001b
	residual	11727318.02	259	45279.22		
	total	13076166.93	269			

By recording the year, soil depth, forest type, pH value, soil temperature, soil humidity, soil organic matter, litter N content, litter carbon content, and litter C/N content as independent variables, the linear regression fitting model for all n was constructed. From the linear fitting results in Table 4, Figure 5, and Figure 6, the linear fitting result did not have a strong fit. Although the linear trend change is presented, the line coverage rate is relatively low. The forecast regression value normal distribution is clear, but still has the specific reference value. The p-value is significant at 0.001. The results are shown in Table 9.

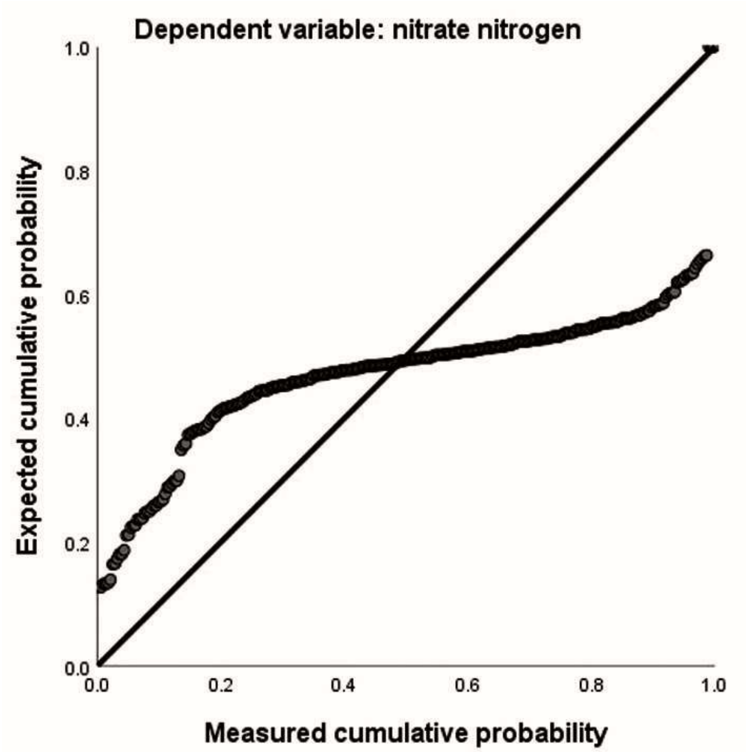

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Figure 5. Normal P-P diagram of regression standardized residuals. .

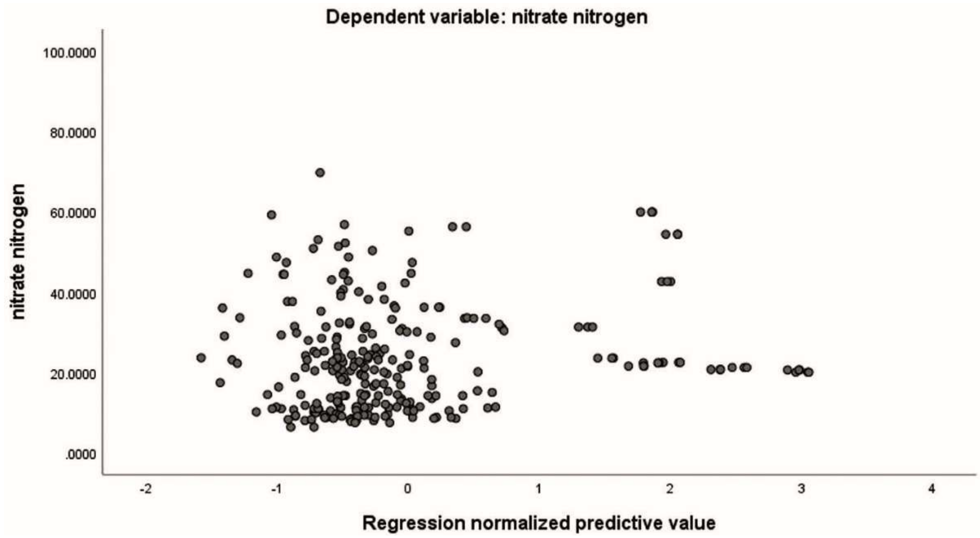

Figure 6. Scatter plot for nitrate nitrogen prediction.

Table 9. Multivariate analysis of variance of soil nitrate nitrogen in the *Picea mongolica* forest (T-Test).

model	Nonstandard Coefficient		Standardized number	t	Significance
	Beta		Beta		
particular year	13.24	47.05	0.10	0.28	0.078
Forest type	4.79	22.44	0.02	0.21	0.083
Soil depth	1.74	1.01	0.11	1.72	0.086
PH value	-39.97	41.03	-0.08	-0.97	0.331
humidity	54.79	15.91	0.41	3.44	0.001
temperature	-2.95	3.22	-0.14	-0.92	0.036
Litter N content	-30.05	122.53	-0.05	-0.25	0.081
Litter N content	-3.92	6.76	-0.45	-0.58	0.056
Litter CN ratio	12.71	23.19	0.54	0.55	0.058
Soil organic matter content	-0.29	0.27	-0.08	-1.06	0.029

From the linear fitting results in Table 5, humidity, temperature, and CN ratio of litter and organic matter have a considerable impact on the total N, and the highest contribution rate. The impact of litter N content and pH value is slightly lower, but the *p*-values for all other influencing factors, with the exception of litter N content, are greater than 0.05, indicating a significant result.

3.4. Correlation between soil total N, NH_4^+—N，NO_3^-—N content and month, soil depth and forest age

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Table 10. Correlation coefficient between nitrogen stoichiometry in the soil of *Picea mongolica* forest and influencing factors *at level 0.05 (two-tailed) with a significant correlation. * * At the 0.01 level (two-tailed), the correlation was significant.

	particular year	**Soil depth**	**Forest type**	**total N**	**NNH4N**	**NNO3N**	**PH**	**temperature**	**humidity**	**Litter C content**	**Litter N content**	**Litter C/N**	**Soil organic matter content**
particular year	1	0	0	0.394**	0.11	0.44**	-0.164**	0.251**	0.258**	-0.957**	0.919**	-0.973**	0.052
Soil depth		1	0	-0.001	-0.228**	0.06	0.248**	-0.057	-0.165**	-0.76	-0.62	-0.71	-0.359**
Forest type			1	0.21	0.47**	0.006	-0.285**	0	-0.047	-0.196**	0.124*	-0.158**	0.166**
total N				1	0.037	-0.005	-0.029	0.078	0.008	-0.120*	0.093	-0.129*	0.066
NNH4N					1	-0.037	-0.222**	0.236**	0.388**	-0.002	-0.013	-0.005	0.264**
NNO3N						1	-0.140*	0.157**	0.265**	-0.038	0.024	-0.044	-0.012
PH							1	-0.246**	-0.413**	0.237**	-0.280**	0.229**	-0.531**
temperature								1	0.819**	-0.185**	0.072	-0.266**	0.205**
humidity									1	-0.197**	0.130*	-0.255**	0.233**
Litter C content										1	-0.941**	0.993**	-0.086
Litter N content											1	-0.934**	0.119
Litter C/N												1	-0.085
Soil organic matter content													1

The total soil N in the *Picea mongolica* forest has a positive correlation with the year, with a correlation coefficient of 0.394, a significant negative correlation with litter C content and litter CN ratio, with correlation coefficients of -0.120 and -0.129 respectively, and a positive correlation with ammonium N, temperature, humidity, litter N content, and soil organic matter content (Table 10). However, there is no significant correlation with soil depth, nitrate N, and pH value also showing a negative correlation. NH_4^+—N had a significant negative correlation with soil depth and pH value, and the correlation coefficients were 0.228 and -0.222 respectively. There was a significant positive correlation with forest type, temperature, humidity, and soil organic matter content, and the correlation coefficients were 0.47, 0.236, 0.388, and 0.264 respectively. There was little positive correlation with years, but with nitrate N, litter C content, and litter N content, the litter CN rate showed a negative correlation. NO_3^-—N had a positive correlation with year, temperature, and humidity, with clear significance. The correlation coefficients were 0.44, 0.157, and 0.265 respectively. There was a significant negative correlation with pH, with a correlation coefficient of -0.140. There was a weak positive correlation with soil depth, forest stand, and litter N content, and a weak negative correlation with total N, ammonium N, litter C content and litter CN rate.

4. Discussion

4.1. Effects of litter addition on the contents of total N, NH_4^+—N and NO_3^-—N in the soil of Picea mongolica forest

Forest litter is the main source of soil nutrients, and nutrients are returned to the soil following decomposition. This study found that there was a positive correlation between litter N content and soil organic matter, total N content, and NO_3^-—N content across different forest ages. High N content in the litter and high soil organic matter, total N, and NO_3^-—N contents were observed. There was a negative correlation between litter N and

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NH_4^+—N contents. A negative correlation between litter C content and soil organic matter, total N, and NO_3^-—N contents was also observed. In this study, the total N and NO_3^-—N increased with the increase of N content during litter decomposition. The results are similar to those of different tree species studied by Pan et al. [4] and Magill et al. [15]. It is possible that N input increases the content of mineral N in the soil and litter layers, buffering the competition between plant absorption and nitrobacteria, as well as denitrifying bacteria for N, increasing nitrification and denitrification, and then increasing soil-available N [16]. This may also be related to the mineralization and fixation of N. The addition of N improves the soil nitrification process, resulting in more N in the form of NO_3^-—N [17]. As the increased N is absorbed by soil organic matter, C/N decreases, which improves the release rate of N during decomposition [18]. It is also possible that the added inorganic N is fixed by microorganisms, which promotes the mineralization and release of the original organic N [19].

4.2. *Effects of environmental factors on the contents of total N, NH_4^+—N and NO_3^-—N the soil of Picea mongolica forest*

The change in soil N content is affected by various environmental factors such as soil temperature, moisture, and pH. Differences in temperature, humidity, and litter supply in different niches affect N mineralization by influencing he number, species, and vitality of different microbial groups in the forest [18].

In this study, a positive correlation was observed between temperature and soil total N, NH_4^+ —N, and NO_3^-—N. The contents of total N, NH_4^+—N, and NO_3^-—N increased with increasing temperature. This was similar to the research results of Zhao et al. [20]. The highest contents of total N, NH_4^+—N, and NO_3^-—N on the soil surface of young, middle-aged, and near-mature forests were all recorded in July. This may be because the increase in temperature increases the availability of soil ammonia N and nitrate N, as the NH_4^+—N of forest soil ammonification is the source of nitrification, with ammonification directly affecting the change in nitrification rate. The nitrification rate is often lower than the ammoniation rate [21]. The increase in temperature promotes the denitrification of the surface soil. In addition, when the temperature increases, the microbial growth and metabolism activity is enhanced and a large amount of organic matter is decomposed. whichThis improves the mineralization rate of soil N and significantly increases the content of N in the soil [22].Temperature change can also change the mineralization rate of N in the soil by affecting soil water content [21].

Soil moisture content is an important factor in the process of soil N transformation. In this study, the soil total N, NH_4^+—N, and NO_3^-—N were positively correlated with soil moisture, and the contents of NH_4^+—N and NO_3^-—N were significantly correlated with soil moisture. This may be because the joint action of soil water content and other soil physical and chemical properties can significantly alter the porosity and pore distribution of soil. This affects the circulation of oxygen in soil, which in turn affects the activity of microorganisms [23].The short-term increase in temperature and water can significantly improve the activity of soil microorganisms, which is conducive to their growth and reproduction. This can change the contents of soil total N, NH_4^+—N, and NO_3^-—N. As drought and low temperatures weaken biological activities, the litter decomposition rate decreases to a certain extent with low temperatures during winter (November) and during low precipitation (May).

Soil pH and other pH can directly or indirectly affect other properties and are the main variables affecting soils [24,25]. In this study, soil pH was negatively correlated with soil total N, NH_4^+—N, and NO_3^-—N, as well as with NH_4^+—N and NO_3^-—N. This is similar to the research results of Chen et al. [26]. Lower pH will limit the growth of soil denitrifying microorganisms. However, lower pH may reduce the availability of organic carbon and mineral N available to denitrifying microorganisms [27].

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4.3. Effects of seasonal variation on the contents of total N, NH_4^+—N and NO_3^-—N in the soil of *Picea mongolica* forest

In the current study, the total N content of *Picea mongolica* forest across three different stand ages increased first and then decreased over time during 2017. The total N content for the three forest ages was the highest during May and July. This is because the N element mainly exists in the form of organic matter, and its release needs to be decomposed by microorganisms. In summer, microbial activity begins to increase, which promotes the decomposition of the N element [28]. The content of NH_4^+—N across the three forest ages and in each soil layer is greater than that of NO_3^-—N, which is consistent with the research results of Zhao et al. [11]. This indicates that NH_4^+—N is the main form of soil available n. Correlation analysis showed that seasonal dynamic changes had an effect on the NH_4^+—N and NO_3^-—N in the *Picea mongolica* soil layer. The content was lower than in March and November, and higher during May and July. This is consistent with the results for two n elements in temperate forest soil studied by Xu et al. [3]. This may be because the weather warmed up during May, the snow melted, the soil temperature and humidity increased at the same time, the soil microbial activity began to increase, and the N mineralization, especially the ammoniation, increased [16]. This resulted in a large amount of decomposition of the N in the litter, and the contents of NH_4^+—N and NO_3^-—N in sandy spruce soil for each forest age would have increased. The *Picea mongolica* then entered the growing season, and with the continuous increase of temperature, it needs to absorb a large amount of NH_4^+—N [30,31]. Part of the NH_4^+—N is transformed into NO_3^-—N through the action of nitrifying microorganisms. With the increase in rainfall, NH_4^+—N and NO_3^-—N entered the deep soil layer through the leaching of rainwater. The NH_4^+—N content then decreases to a certain extent. The high content during July was due to the slow growth of spruce on sandy land during autumn. The reduction in NH_4^+—N absorption and its relative accumulation, is consistent with the results of NH_4^+—N and NO_3^-—N in temperate forest soils studied by Xu et al. [3]. In November, the contents of NH_4^+—N and NO_3^-—N in sandy spruce soils were 0–20 cm. The contents of the soil surface layer was greater than that at depths of 30–50 cm. The main reason for this is that the northern temperate zone enters winter in October, the weather is cold and the soil is covered with ice and snow. Low temperatures will inhibit the activities of soil microorganisms, weaken the humic effect and slow decomposition rates, which hinders the mineralization of soil [30].

4.4. Effect of soil depth on the contents of total N, NH_4^+—N and NO_3^-—N in the soil of *Picea mongolica* forest

Results showed that the total N, NH_4^+—N and NO_3^-—N in *Picea mongolica* soils decreased with increasing soil depth (0–50 cm), There were significant differences between 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, and 40–50 cm soil layers ($p<0.05$). This is consistent with trends in soil N content with increasing soil depth in forests in the Qinghai Province as well as the alpine forests in Western Sichuan [31,32]. This is because the process of decomposition and synthesis of litter returns n to the soil. On the soil surface, the N content mainly comes from litter decomposition. While litter is mainly concentrated on the soil surface, nutrients also accumulate there. Good ventilation and hydrothermal conditions on the soil surface provide a better environment for microbial activities, therefore promoting the accumulation of N content at the soil surface. Then the N migrates and diffuses down to the mineral soil layer with water or other media. In the deeper soil layers, the N content is mainly derived from roots, root exudates, soil microorganisms and N leaching from some of the upper layers. Compared with the soil surface layer, the exchange with the outside world is weak [33]. In addition, with the deepening of the soil layer, plant roots, soil animals and microorganisms absorb and utilize nutrients. As a result, the total N, NH_4^+—N and NO_3^-—N in *Picea mongolica* soils decreased with the increase in soil depth (0–50 cm). This is consistent with the results of Qin et al. [34] on soil nutrients in different forest types with Masson pine (*Pinus massoniana* Siebold & Zucc.).

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4.5. Effects of forest age on the contents of total N, NH_4^+—N and NO_3^-—N in the soil of *Picea mongolica* forest

This study has shown that the content of soil NH_4^+—N during March and November 2017 was significantly different from that of May and August 2017 ($p < 0.05$).The NH_4^+—N content in the soil of the *Picea mongolica* forest generally showed a trend of near-mature forest > middle-aged forest > young forest. The trend in soil NO_3^-—N content is consistent with that of sandy spruce soil NH_4^+—N content. This is similar to the results for different tree species studied by Pan et al. [4], Wang et al. [35] and Cui et al. [36]. This may be that during the growth of the *Picea mongolica* forest, the biomass gradually increased, the soil surface litter and animal and plant residues gradually increased, the soil texture has been greatly improved, and the number and variety of microorganisms are various and active. They decompose the soil surface litter and animal and plant residues, resulting in an increase in soil nutrients NH_4^+—N and NO_3^-—N [4,37,38]. Due to the demand for N in different growth stages of *Picea mongolica*, the demand for soil N in young and middle-aged forest stages is high. After the forest has reached maturity, due to the slow and stable growth of *Picea mongolica*, the utilization rate of soil N may be lower. In addition, the deeper the soil has roots growing in the near-mature forest of *Picea mongolica*, the more conducive it is to the absorption of deep-seated soil nutrients. This also leads to the highest contents of NH_4^+—N and NO_3^-—N at the soil surface when the forest reaches maturity [35].

The total N and ammonia N in the soils were found to be higher in the near-mature forest and middle-aged forest. In the young forest, it was found to be lower. This may be because plants at different growth stages have different nutrient needs, which can lead to differences in nutrient content in their own organs and litter [4].

5. Conclusions

(1) Total N and NH_4^+—N in the soil of *Picea mongolica* forest were positively correlated with month, soil NO_3^-—N and forest age ($p<0.05$), and negatively correlated with soil depth ($p<0.01$). NO_3^-—N in *Picea mongolica* soil was negatively correlated with month and stand age ($p < 0.05$), and significantly negatively correlated with soil depth ($p<0.01$).

(2) The NH_4^+—N in each soil layer for *Picea mongolica* forest across the three forest ages is greater than that of NO_3^-—N. The correlation analysis shows that the seasonal dynamic change has an impact on the of soil NH_4^+—N and NO_3^-—N contents of the *Picea mongolica* forest. The content was lower during February and November, and higher in May and August.

(3) The total N, NH_4^+—N, and NO_3^-—N in sandy spruce soil for the three forest ages increased with the depth of the soil layer (0–50 cm) and showed an overall downward trend. Significant differences ($p < 0.05$) in NH_4^+—N content between 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, and 40–50 cm soil layers in young forest were observed. NO_3^-—N content also showed a significant difference ($p < 0.05$), but there was no significant difference in NH_4^+—N content between middle-aged forest and near-mature forest with increasing soil depth.

(4) The content of N, NH_4^+—N in the soil of the *Picea mongolica* forest generally showed a trend of near-mature forest > middle-aged forest > young forest. The trend for soil NO_3^-—N content is consistent with that of NH_4^+—N content in the soil of *Picea mongolica* forest.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Table S1: Key vegetation parameters of the sampling plots; Table S2: Mean air temperature and precipitation in different months; **Table S3.** Soil ammonium nitrogen and nitrate nitrogen contents and their vertical distribution in different stand ages and times in young forest (Y-F); middle-aged forest (M-F); and near-mature forest (N-F).

Author Contributions: Conceptualization,. Lixin Chen and Yunchao Liu.; methodology, Yunchao Liu.; validation, Yunchao Liu., Lixin Chen. and Wenbiao Duan.; formal analysis, Xiaolan Li.; investigation, Yongan Bai and Yunchao Liu.; resources, Yunchao Liu，Lixin Chen, Wenbiao Duan and Yongan Bai.; data curation, Yunchao Liu and Xiaolan Li.; writing—original draft preparation, Yunchao Liu.; writing—review and editing, Yunchao Liu., Lixin Chen. and Wenbiao Duan.; visualization, Yunchao Liu., Lixin Chen. and Wenbiao Duan.; supervision, Wenbiao Duan.; project administration, Yunchao Liu.and Yongan Bai ;. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by The Natural Science Foundation of Inner Mongolia (Project 2017MS0327). And The Inner Mongolia autonomous region of institutions of higher learning scientific research projects （Project NJZZ22176）

Data Availability Statement: Not applicable.

Acknowledgments We are grateful to friends who assisted with fieldwork, especially Yichao Wang. We thank the Baiyinaobao National Nature Reserve Management Administrationstaff for enabling this research.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Grant, R.F. Nitrogen Mineralization Drives the Response of Forest Productivity to Soil Warming: Modelling in Ecosysvs． Measurements from the Harvard Soil Heating Experiment. *Ecol. Modell.* **2014**, *288*, 38–46. https://. DOI:10.1016/j.ecolmodel.2014.05.015.

2. Ma, H.F.; Xie, M.Y.; Hu, H.; Guo, Y.X.; Ren, C.J.; Zhao, F.Z. Effects of Stoichiometric Characteristics of Soil plant□litter on soil nitrogen components in different forests along an elevational gradient of Qinling Mountains. *Chin. J. Ecol.* **2020**, *39*, 749–757. Available online: http://www.cje.net.cn/CN/Y2020/V39/I3/749.

3. Xu, C.Q.; Chen, L.X.; Yan, Y.Q.; Ji, X. (2008Seasonal dynamic characteristics of ammonium-nitrogen and nitrate nitrogen contents in soil in temperate forests. *J. Northeast For. Univ.* **2008**, 19–21.

4. Pan, F.J.; Liang, Y.M.; Ma, J.M.; Yang, Z.Q.; Ling, T.W.; Li, M.J.; Lu, S.H.; Zhong, F.Y. Stand Age and Density Affected Litter Nutrient Changes in Planted Pinus Massoniana Forests. *Guihaia*. **2020**, *40*, 237–246. DOI:10.11931/guihaia.gxzw201906044.

5. Yang, X.; Chen, L.H.; Zheng, X.L. Ecological Stoichiometry Characterization of Soil Carbon, Nitrogen, and Phosphorus of *Pinus tabuliformis* Plantations at Different Stand Ages. *Sci. Soil Water Conserv.* **2021**, *19*, 108–116. DOI:10.16843/j.sswc.2021.02.014.

6. Fang, L.N.; Yang, X.D.; Du, J. Effects of Land Use Pattern on Soil Microbial Biomass Carbon in Xishuangbanna. *Ying Yong Sheng Tai Xue Bao*. **2011**, *22*, 837–844. DOI:10.13287/j.1001-9332.2011.0080.

7. Xu, J.F.; Zhao, J.H.; Yuan, Z.X.; Jin, X.M.; Chen, B.; Guan, Q.W.; Gao, Y. Effects of Tree Species and Landuse Patterns on Soil Microbial Biomass Carbon & Nitrogen. *J. Cent. S. Univ. For. Technol.* **2018**, *38*, 95–100. DOI:10.14067/j.cnki.1673-923x.2018.04.016.

8. Hu, Y.S.; Yao, X.Y.; Liu, Y.H. N and P Stoichiometric Traits of Plant and Soil in Different Forest Succession Stages in Changbai Mountains. *Chin. J. Appl. Ecol.* **2014**, *25*, 632–638. Available online: http://www.cjae.net/CN/Y2014/V25/I3/632.

9. Xue-Mei, W.; Bang-Guo, Y.; Guang, Z.; Liang-Tao, S.; Gang-Cai, L.; FANG Hai-Dong, a. Effects of Microorganism on Carbon, Nitrogen and Phosphorus of *Dodonaea viscosa* and the Soils from Different Elevations in Yuanmou, Yunnan, China. *Chin. J. Plant Ecol.* **2017**, *41*, 311–324. Available online: https://www.plant-ecology.com/CN/Y2017/V41/I3/311. DOI:10.17521/cjpe.2016.0267.

10. Zhang, S.S.; Li, A.Q.; Wang, H.R.; Wang, J.J.; Xu, X.N. Ecological Stoichiometry of Soil Carbon, Nitrogen and Phosphorus in Cunninghamia lanceolata Plantation Across an Elevation Gradient. *Ecol. Environ. Sci.* **2020**, *29*, 97–104. DOI:10.16258/j.cnki.1674-5906.2020.01.011.

11. Zhao, W.J.; Liu, X.D.; Jing, M.; Zhang, X.L.; Che, Z.X.; Jing, W.M.; Wang, S.L.; Niu, Y.; Qi, P.; Li, W.J. Ecological Stoichiometric Characteristics of Carbon, Nitrogen and Phosphorus in Leaf-Litter-Soil System of *Picea crassifolia* Forest in the Qilian Mountains. *Acta Pedol. Sin.* **2016**, *53*, 477–489. DOI:10.11766/trxb201501080511.

12. Meng, Y.; Xue, J.Y.; Sha, L.Q.; Tang, J.W. Variations of Soil NH4-N, NO3−—Nand N Mineralization Under Different Forests in Xishuang-banna, Southwest China. *Chin. J. Plant Ecol.* **2001**, *25*, 99–104. Available online: https://www.plant-ecology.com/CN/Y2001/V25/I1/99.

13. Castro, H.F.; Classen, A.T.; Austin, E.E.; Norby, R.J.; Schadt, C.W. Soil Microbial Community Responses to Multiple Experimental Climate Change Drivers. *Appl. Environ. Microbiol.* **2010**, *76*, 999–1007. DOI:10.1128/AEM.02874-09.

14. Bai, X.F.; Xu, F.L.; Wang, W.L.; Zhao, Y.F.; Wang, L.L.; Sun, P.Y. Ecological Stoichiometry of Soil Carbon, Nitrogen and Phosphorus in aLarix Principis Rupprechtii Plantation. *Sci. Soil Water Conserv.* **2015**, *13*, 68–75. DOI:10.16843/j.sswc.2015.06.011.

15. Magill, A.H.; Aber, J.D.; Berntson, G.M.; McDowell, W.H.; Nadelhoffer, K.J.; Melillo, J.M.; Steudler, P. Long-Term Nitrogen Additions and Nitrogen Saturation in Two Temperate Forests. *Ecosystems*. **2000**, *3*, 238–253. DOI:10.1007/s100210000023.

16. LIU Zhijiang, 刘; LIN Weisheng, 林; YANG Zhouran, 杨; LIN Tingwu, 林; LIU Xiaofei, 刘; CHEN Yuehmin, 陈; YANG Yusheng, 杨. Effects of Soil Warming and Nitrogen Deposition on Available Nitrogen in a Young *Cunninghamia lanceolata* Stand in Mid-Subtropical China. *Acta Ecol. Sin.* **2017**, *37*, 44–53. DOI:10.5846/stxb201512302599.

17. Zhang, G.S.; Deng, H.J.; Du, K.; Lin, Y.M.; Ma, R.F.; Yu, W.; Wang, D.J.; Wu, C.Z.; Hong, W. Soil Stoichiometry Characteristics at Different Elevation Gradients of a Mountain in an Area with High Frequency Debris Flow: a Case Study in Xiaojiang Watershed, Yunnan. *Acta Ecol. Sin.* **2016**, *36*, 675–687. DOI:10.5846/stxb201405060892.

18. Chen, L.X.; Huang, L.Y.; Qiao, L.; Duan, W.B.; Ji, X.; Yu, Y.C. Influence of Simulated Nitrogen Deposition Mineralization Rate Under Different Temperate Forest Stands. *J. Soil Water Conserv.* **2012**, *26*, 139–146. DOI:10.13870/j.cnki.stbcxb.2012.06.039.

19. Zhang, L.; Huang, J.H.; Bai, Y.F.; Han, X.G. Effects of Nitrogen Addition on Net Nitrogen Mineralization in Leymus chinensis Graassland, Inner Mongolia, China. *Chin. J. Plant Ecol.* **2009**, *33*, 563–569. Available online: https://www.plant-ecology.com/CN/Y2009/V33/I3/56.

20. Zhao, W.J.; Liu, Y.T.; Tan, C.J. Cui YiC, Wu P, Hou YJ, Liu YH, Ding JJ. *J. Cent. S. Univ. For. Technol.* **2021** Effects of simulated nitrogen deposition on soil nitrogen mineralization in karst primary forest., *41*, 124–133. DOI:10.14067/j.cnki.1673-923x.2021.07.015.

21. Fang, Y.T.; Mo, J.M.; Zhou, G.Y.; Per Gundersen, L.D.J.; Jiang, Y.Q. The Short-Term Responses of Soil Available Nitrogen of Dinghushan Forests to Simulated N Deposition in Subtropical China. *Acta Ecol. Sin.* **2004**, *24*, 73–80.

22. Hester, E.R.; Harpenslager, S.F.; van Diggelen, J.M.H.; Lamers, L.L.; Jetten, M.S.M.; Lüke, C.; Lücker, S.; Welte, C.U. Linking Nitrogen Load to the Structure and Function of Wetland Soil and Rhizosphere Microbial Communities. *mSystems*. **2018**, *3*, e00214–17. DOI:10.1128/mSystems.00214-17.

23. Barton, L.; Murphy, D.V.; Butterbach-Bahl, K. Influence of Crop Rotation and Liming on Greenhouse Gas Emissions from a Semi-Arid Soil. *Agric. Ecosyst. Environ.* **2013**, *167*, 23–32. DOI:10.1016/j.agee.2013.01.003.

4ŠImek, M.; Cooper, J.E. The Influence of Soil pH on Denitrification: Progress Towards the Understanding of This Interaction over the Last 50 Years. *Eur. J. Soil Sci.* **2002**, *53*, 345–354. DOI:10.1046/j.1365-2389.2002.00461.x.

25. Deng, X.H.; Cai, X.; Tian, F.; Cai, Y.F.; Tian, M.H.; Zhang, L.M.; Zhang, M.F. pH and Main Nutrients of Tobacco-Growing Soils and Their Relations in Western Hunan. *Soils*. **2017**, *49*, 49–56. DOI:10.13758/j.cnki.tr.2017.01.008.

26. Chen, G.T.; Li, S.; Peng, T.C.; Qiu, X.R.; Chen, Y.Q.; Ma, H.Y.; Tu, L.H. Effect of Root Isolation and Nitrogen Addition on Soil Carbon and Nitrogen Component in a Moist Evergreen Broad-Leaved Forest. *Chin. J. Appl. Environ. Biol.* **2018**, *24*, 125–131. DOI:10.19675/j.cnki.1006-687x.2017.04021.

27. Xu, Y.B.; Xu, Z.H.; Cai, Z.C. Progresses in Research on Denitrification in Tropical and Subtropical Soils of Terrestrial Ecosystems. *Ecol. Environ. Sci.* **2014**, *23*, 1557–1566. Available online: http://www.jeesci.com/CN/Y2014/V23/I9/1557.

28. Wang, X.; Gao, M.D.; Yang, F.; Guo, Y.P.; Ma, C.M. Litter Decomposition and Nutrient Dynamics of Larix Principis-Rupprechtii Plantations of Different Ages. *J. Northeast For. Univ.* **2012**, *40*, 56–60 + 66. DOI:10.13759/j.cnki.dlxb.2012.10.030.

29. Marschner, H.; Haussling, M.; George, E. Ammonium and Nitrate Uptake Rates and Rhizosphere pH in Non-Mycorrhizal Roots of Norway Spruce [Picea Abies (L.)Karst.]. *Trees*. **1991**, *5*, 14–21. DOI:10.1007/BF00225330.

30. Glass, A.D.M.; Siddiqi, M.Y. 1995. *Nitrogen Absorption by Plant Roots//Srivastava H S, Singh R P*，eds．Nitrogen Nutrition in Higher Plants．New Delhi，India: Associated Publishing Co, 21–56.

31. Li, X.Y.; Zhang, W.Y.; Liu, F.; Zhang, Z.M.; He, T.B.; Lin, C.H. The Distribution Characteristics of Soil Carbon, Nitrogen and Phosphorus at Different Altitudes in Fanjing Mountain. *Res. Soil Water Conserv.* **2016**, *23*, 19–24. DOI:10.13869/j.cnki.rswc.2016.03.004.

32. Wang, Y.L.; Zi, H.B.; Cheng, R.X.; Tang, L.T.; Suoer Azhi, L.X.P.; Li, J.; Wang, C.T. Forest Soil Organic Carbon and Nitrogen Storage and Characteristics of Vertical Distribution in Qinghai Province. *Acta Ecol. Sin.* **2019**, *39*, 4096–4105. DOI:10.5846/stxb201803240583.

33. Wang, S.P.; Zhou, G.S.; Lu, Y.C.; Zou, J.J. Distribution of Soil Carbon, Nitrogen and Phosphorus Along Northeast China Transect (NECT) and Their Relationships with Climatic Factors. *Chin. J. Plan Ecol.* **2002**, *26*, 513–517. Available online: https://www.plant-ecology.com/CN/Y2002/V26/I5/513.

34. Qin, J.; Kong, H.Y.; Liu, H. Stoichiometric Characteristics of Soil C, N, P and K in Different Pinus Massoniana Forests. *J. Northwest. Agric. For. Univ.* **2016**, *44*, 68–76. doi. DOI:10.13207/j.cnki.jnwafu.2016.02.010.

35. Wang, P.A.; Ren, X.M.; Bo, F.J.; Zhang, Y.X.; Guo, J.P. *Analysis on Soil Stoichiometric Characteristics and Soil Physico Chemical Properties of Larix Principis-Rupprechtii Plantations in Different Forest Ages in Guandi Mountain*; Vol. 48; Shanxi Agricultural Sciences, 2020; pp. 956–963.

36. Cui, N.J.; Zhang, D.J.; Liu, Y.; Zhang, J.; Ou, J.; Zhang, J.; Deng, C.; Ji, T.W. Plant Diversity and Soil Physicochemical Properties Under Different Aged *Pinus Massoniana* Plantations. *Chin. J. Ecol.* **2014**, *33*, 2610–2617. Available online: http://www.cje.net.cn/CN/Y2014/V33/I10/2610.

37. Wang, D.; Dai, W.; Wang, B.; Li, P.; Deng, Z.F.; Zhao, C. Changes of Soil Properties at Different Developmental Stages of Chinese Fir Plantations. *J. Beijing For. Univ.* **2010**, *32*, 59–63. DOI:10.13332/j.1000-1522.2010.03.037.

38. Peng, Y.H.; Tan, C.Q.; Shen, W.H.; Zheng, W.; He, Q.F.; He, F.; Chen, S.G. Effects of Differt Forest Age on Soil Physical and Chemical Properties of Cunninghamia lanceolata Plantations. *Guangxi For. Sci.* **2020**, *49*, 361–367. DOI:10.19692/j.cnki.gfs.2020.03.009.