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Regional Scale Determinants of Nutrient Content of Soil in a Cold-Temperate Forest

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Abstract: The effect of climatic factors on soil nutrients is significant. Identifying whether soil nutrients respond to local climate and how the forest types modulate this responsiveness is critical for forest management. Therefore, six soil nutrients from five main forest types found for a range of sites within the Daxing'an Mountains, China, were investigated. Climatic factors were obtained from the WorldClim dataset. Pearson correlations and stepwise regressions were employed to elucidate and model the response of the six soil nutrients to the four different climatic factors in this study. On the whole, climate was correlated with all the nutrients. Further, from stepwise regressions, climatic factors could affect soil nutrients in distinct forests. Our findings suggest that climatic factors are instrumental in affecting soil nutrients in different forest types. Identifying the relationships between soil nutrients, climatic factors and forest types, as suggested in this research, can provide theoretical foundations to further comprehend nutrient cycling in the forest ecosystem.

Keywords: Daxing'an Mountains; climatic factors; soil nutrients; forest types; principal component analyses

1. Introduction

Climate changes have significant effects on ecosystems. In the present paper, with the primary focus on the links between ecosystems and climate change, gradients of natural climate are noteworthy in studying the interactions between climate and variation in forest ecosystem processes. Terrestrial ecosystems play a dominant and irreplaceable role, due to the functions of releasing and absorbing greenhouse gases in such climate-feedbacks, while storing a great deal of carbon in vegetation and soil, thus serving as the global carbon sink [1]. Some studies have shown that there are strong linkages between climate change and soil. The study of Brittany et al. showed that the gradient of climates (precipitation and temperature) has obvious regulating effects on the physical and chemical properties of soil, such as pH, Mg²⁺, N, P and K content [2]. The effects of climatic factors on SOC (soil organic carbon) density were obvious and stronger than those of grassland and farmland [3]. Furthermore, regression analysis showed that temperature has a negative correlation with SOC content, and precipitation has a positive correlation with SOC content, but using multiple regression analysis, temperature and precipitation explained 43% of total variance in the SOC variables [4,5]. Soil organic matter related to SOC, total nitrogen (TN), total phosphorus (TP), total potassium (TK), available P (AP) and available K (AK) has been extensively used to evaluate soil quality [6–9]. Moreover, forest

types can impact the cycling and amounts of the nutrients, and nutrients have been confirmed to be influenced by the upper layer [10]. However, the impacts of tree species upon soil nutrients varied depending upon the type of bedrock, climate and forest management [11]. Therefore, understanding the relationships between soil nutrients and climate change in different forest types will provide more reliable information to prudently manage forest resources and promote sustainable forestry development under climate change in the future.

The Daxing'an Mountains forest area is in the mid-latitude and high-latitude area that is extremely sensitive to global warming [12]. The Daxing'an Mountains forest area is the main forest in China. It plays an important role in carbon sequestration management and ecological environment construction. Nevertheless, under the influence of climate change, the edge of the forest has retreated 140 km over the past century in this region [13]. Therefore, the soil nutrients of different vegetation types in this region have attracted widespread attention. Jiang et al. [14] studied the soil nutrients of different forests. However, there is less research focused on the soil nutrient characteristics in different forest types in the Daxing'an Mountains forest area. Although the distribution of SOC, N, P, and K in the Liaodong Mountains area [15] and the correlations between SOC, inorganic carbon and soil nutrients in the northeast of China [16] have been studied, studies reporting research related to the comprehensive evaluation of soil nutrients from different forest types in the Daxing'an Mountains forest area are scarce.

In this study, the soil nutrients of a total of 230 sample plots collected from five main forest types were measured from the Daxing'an Mountains, and four bioclimatic variables (mean annual temperature (MAT), temperature seasonality (TS), mean annual precipitation (MAP) and precipitation seasonality (PS)) were obtained from the WorldClim dataset. We hypothesized that climatic factors could affect soil nutrients in different forest types. Thus, identifying whether soil nutrients respond to local climate and how the forest types modulate this responsiveness is critical for forest management.

2. Methods

2.1. Site Description

The forest in the Daxing'an Mountains is one of the most important areas in China: the lush natural forest is distributed widely. It is an important production base for forest trees in China, and also an important ecological barrier in northeastern China. The study area comprises about 86,000 km² and belongs to the cool coniferous forests. The investigated forest plots are shown in detail in Figure 1 [17]. Five main forest types were chosen, including pure *Larix gmelinii* (Rupr.) Kuzen forest (PL) (87 samples, altitude: 235–1023 m), pure *Betula platyphylla* Suk. forest (PB) (64 samples, altitude: 160–1003 m), pure *Quercus mongolica* Fisch. ex Ledeb. forest (PQ) (36 samples, altitude: 240–771 m), *Larix gmelinii* (Rupr.) Kuzen and *Betula platyphylla* Suk. mixed forest (MLB) (25 samples, altitude: 247–1038 m) and pure *Pinus sylvestris* L. var. *mongolica* Litv. forest (PP) (18 samples, altitude: 296–905 m). The study was conducted in the eastern forest zones of the Daxing'an Mountains area (45°59'–53°19' N, 119°47'–130°53' E), Heilongjiang Province and Inner Mongolia Autonomous Region. This region has a continental monsoon climate, and receives a mean annual precipitation (MAP) of 764 mm. The temperature varies between −41 °C in January–February and 35 °C in July–August, with a mean annual temperature (MAP) of −2.8 °C.

2.2. Field Soil Sampling and Preliminary Analysis

The forest-covered area of the Daxing'an Mountains was systematically divided into 30 km × 30 km grids using ArcGIS 10.0 (Esri, Redlands, CA, USA) as the meshing tool. The exact latitude and longitude for each grid were recorded with a GPS system (Google, Mountain, CA, USA) [18,19]. Soil sample depth was 0–20 cm [3,4], taken from 3–7 plots (30 m × 30 m each) in each 30 km × 30 km grid (total grids = 52), and 3–7 plots were chosen based on the investigation areas. As much as possible, we chose plots from the central region of the grid; the distance of each plot to the edge of the grid must

be more than 15% of the length on the side of the grid. A total of 230 sample plots were included in this study, and the geometric center coordinates for each sample plot were input into Excel, saved in CSV (Comma Separated Value) format, and the ArcGIS 10.0 software was used to extract the climatic data for each sample plot [19].

SOC was determined by external heating with the potassium dichromate oxidation method; TN was determined by the Semi-micro Kjeldahl method; TP and TK were determined by the method of the NaOH melt—Mo-Sb Colorimetry; AP was determined by the method of the HCl-NaOH extracts; AK was determined using the flame photometry method [20,21].

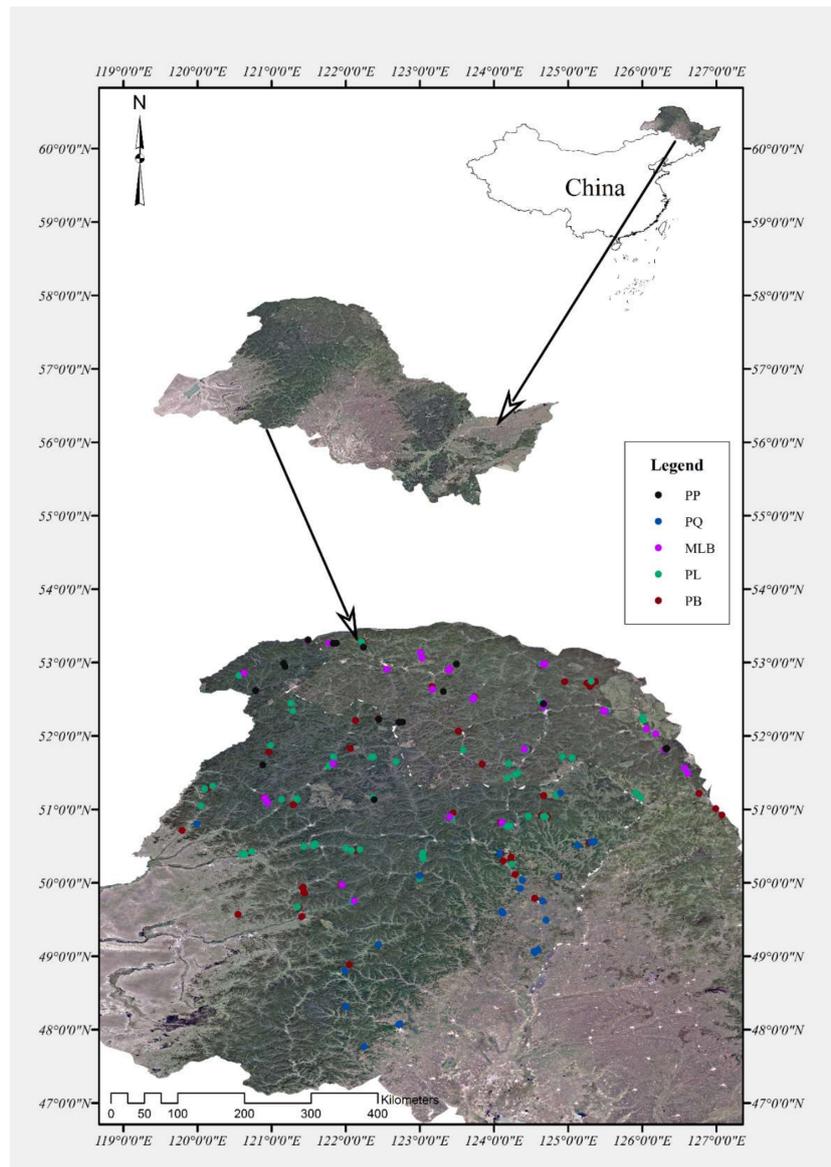


Figure 1. Map of the study area and investigated plots of five forest types in the Daxing'an Mountains. PP = pure *Pinus sylvestris* L. var. *mongolica* Litv. forest, PQ = pure *Quercus mongolica* Fisch. ex Ledeb. forest, MLB = *Larix gmelinii* (Rupr.) Kuzen and *Betula platyphylla* Suk. mixed forest, PL = pure *Larix gmelinii* (Rupr.) Kuzen forest, PB = pure *Betula platyphylla* Suk. forest.

2.3. Climatic Data

Climatic data were obtained from the WorldClim database (<http://www.worldclim.org/>), the accuracy class of which is a spatial resolution of approximately 1 km². The WorldClim data

are collected from weather stations across the globe, which include altitude, temperature, and rainfall (period 1950–2000) [22]. In the present study, four bioclimatic variables (MAT, TS, MAP and PS) were considered to assess the current climatic conditions. The IPCC 4th assessment data provided information for the future climate projections [23].

2.4. Statistical Analyses

The multivariate statistical analysis method has been employed to determine the minimum dataset under the hypothesis that soil nutrients significantly impact forest type. Principal component analysis (PCA) has previously been applied in different research fields to identify nutrients in semiarid soils [24,25] and soil pollutant sources [26] as well as to assess the effect of tillage on soil quality and yield [27–30]. Dimension reduction analysis by using the PCA method to reduce the dimensional data and eliminate the redundant data [31,32]. In our research, we built a hypothesis about which principal components (PCs) possess the highest eigenvalues, variables, and absolute eigenvectors and may best express the minimum dataset.

Pearson correlation coefficients were employed to evaluate the correlations between climatic factors and soil nutrients. Analyses of regression are helpful for inspecting differences among group comparisons; therefore, they are suitable for assessing the variation of soil nutrients under diverse climatic factors. To test whether the climatic factors (MAT, TS, MAP, and PS) affected the soil nutrients (SOC, TN, TP, TK, AP, and AK), a simple linear regression was used for each biological element of the 230 sites with the four climatic factors. To study forest types, specifically the response to climate changes, the climate-change response trends were compared among the forest types. The slopes of the regression lines were used to indicate the different responses of forest types to the climate changes. Linear models compared with non-linear models (Spearman Rank Correlation) gave the best regression results. In addition, stepwise regression between climatic factors and soil nutrients in five main forest types was also analyzed (F-to-enter $p \leq 0.05$, F-to remove $p \geq 0.10$).

The statistical analyses were conducted using SPSS 17.0 software, while the graphs were made using OriginPro 9.0 software (OriginLab Corporation, Northampton, MA, USA).

3. Results

3.1. Variation of Soil Nutrients and Climatic Factors in Different Forest Types

In Figure 2, the contents of SOC, TN, TK, TP, AK and AP in five main forest types averaged at $28.23 \text{ g}\cdot\text{kg}^{-1}$, $4.03 \text{ g}\cdot\text{kg}^{-1}$, $26.23 \text{ g}\cdot\text{kg}^{-1}$, $1.70 \text{ g}\cdot\text{kg}^{-1}$, $158.68 \text{ mg}\cdot\text{kg}^{-1}$ and $21.46 \text{ mg}\cdot\text{kg}^{-1}$, respectively. In particular, SOC, TN, TK, TP, AK and AP contents in the PQ were lower than those in the other four forest types.

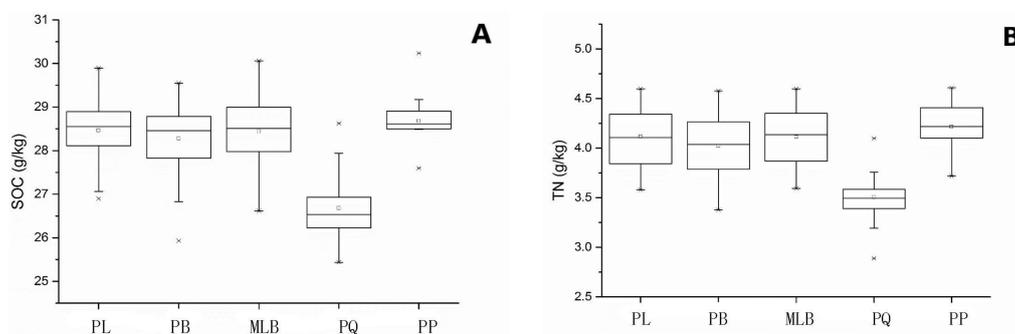


Figure 2. Cont.

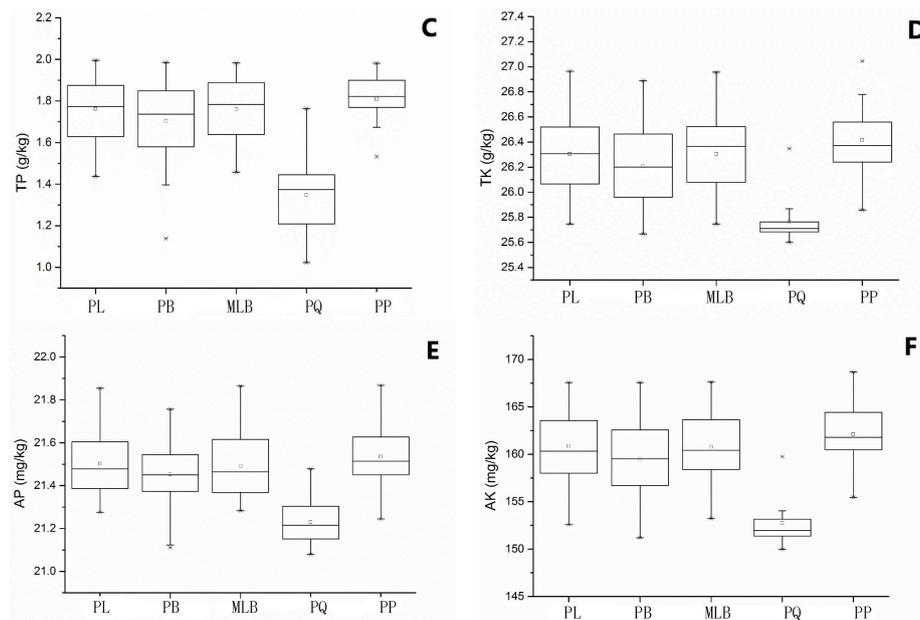


Figure 2. Variation of soil properties in different forest types. SOC = soil organic carbon, TN = total nitrogen, TP = total phosphorus, TK = total potassium, AP = available phosphorus, and AK = available potassium. PP = pure *Pinus sylvestris* L. var. *mongolica* Litv. forest, PQ = pure *Quercus mongolica* Fisch. ex Ledeb. forest, MLB = *Larix gmelinii* (Rupr.) Kuzen and *Betula platyphylla* Suk. mixed forest, PL = pure *Larix gmelinii* (Rupr.) Kuzen forest, PB = pure *Betula platyphylla* Suk. forest. A, B, C, D, E and F were respectively represent for SOC, TN, TP, TK, AP and AK content of five forest types. “□” = average value, “x” = outlier.

The averages of the MAT and MAP were $-1.74\text{ }^{\circ}\text{C}$ and 534.93 mm, respectively; the ranges of the TS and PS were 14,772–16,885 and 95–116, respectively (Figure 3). MAT and PS were higher in the PQ than in the other four forest types, while TS showed the opposite trend (Figure 3).

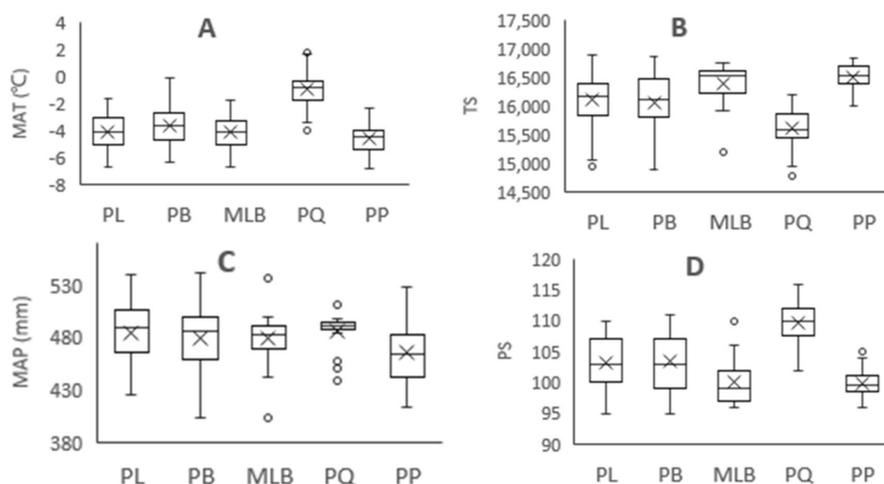


Figure 3. Variation of climatic factors in different forest types. MAT = mean annual temperature, TS = temperature seasonality, MAP = mean annual precipitation, and PS = precipitation seasonality. PL = pure *Larix gmelinii* (Rupr.) Kuzen forest, PB = pure *Betula platyphylla* Suk. Forest, MLB = *Larix gmelinii* (Rupr.) Kuzen and *Betula platyphylla* Suk. mixed forest, PQ = pure *Quercus mongolica* Fisch. ex Ledeb. forest, PP = pure *Pinus sylvestris* L. var. *mongolica* Litv. Forest. A: MAT of five forest types, B: TS of five forest types, C: MAP of five forest types, D: PS of five forest types. “x” = average value, “o” = outlier.

3.2. Principal Component Analysis of the Different Forest Types and the Soil Nutrients

The results of the PCA showed the variables that characterized the soil nutrients of the different forest types (Figure 4). PCs 1–6 explained 100.0% of the variation, and can be broken down as follows: 95.55%, 2.22%, 1.13%, 0.73%, 0.24% and 0.12%, respectively, as shown in Table 1. Principal component 1 can reflect most of the variation; it includes TN (0.296), TK (0.816), TP (−0.263), AP (0.749), AK (0.447) and SOC (−1.302). As shown in Figure 4, five main forest types showed PQ separated from other types.

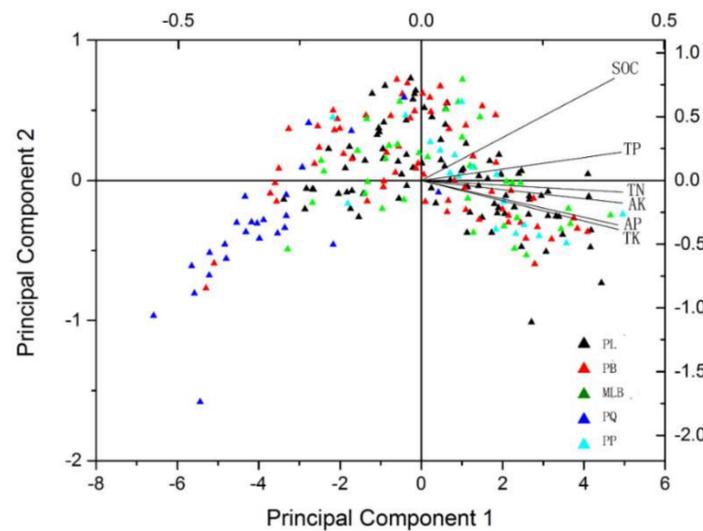


Figure 4. Principal component analysis (PCA) of the different forest types and the soil nutrients. PL = pure *Larix gmelinii* (Rupr.) Kuzen forest, PB = pure *Betula platyphylla* Suk. Forest, MLB = *Larix gmelinii* (Rupr.) Kuzen and *Betula platyphylla* Suk. mixed forest, PQ = pure *Quercus mongolica* Fisch. ex Ledeb. forest, PP = pure *Pinus sylvestris* L. var. *mongolica* Litv. Forest. SOC = soil organic carbon, TN = total nitrogen, TP = total phosphorus, TK = total potassium, AP = available phosphorus, and AK = available potassium.

Table 1. Total variance explained.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.733	95.551	95.551	5.733	95.551	95.551	3.363	56.058	56.058
2	0.133	2.217	97.768	0.133	2.217	97.768	2.503	41.710	97.768
3	0.068	1.134	98.903						
4	0.044	0.733	99.635						
5	0.015	0.244	99.880						
6	0.007	0.120	100.000						

Extraction Method: Principal Component Analysis.

3.3. Correlations between Climatic Factors and Soil Nutrients

The relationships between soil nutrients and climatic factors are shown in Table 2. MAT was negatively correlated with SOC, TN, TK, AK and AP, while it was positively correlated with TP ($r = 0.187$) ($p < 0.01$). TS was positively correlated with SOC, TN, TK, AK and AP ($r = 0.307–0.417$), while it was negatively correlated with TP ($r = -0.405$) ($p < 0.01$). In contrast to TS, the relationships between PS and soil nutrients showed the opposite trend ($p < 0.01$). MAP was positively correlated with SOC, TN, AK and AP, while it was negatively correlated with TK and TP ($p < 0.01$).

Table 2. Correlation coefficient matrix for soil nutrients and climatic factors.

Nutrient	MAT	TS	MAP	PS
SOC	−0.223 **	0.417 **	0.311 **	−0.4700 **
TN	−0.101	0.341 **	0.411 **	−0.414 **
TK	−0.052	0.312 **	−0.411 **	−0.378 **
TP	0.187 **	−0.405 **	−0.383 **	0.471 **
AK	−0.106	0.365 **	0.384 **	−0.425 **
AP	−0.050	0.307 **	0.385 **	−0.367 **

$N = 230$. SOC = soil organic carbon, TN = total nitrogen, TP = total phosphorus, TK = total potassium, AP = available phosphorus, and AK = available potassium. MAT = mean annual temperature, TS = temperature seasonality, MAP = mean annual precipitation, and PS = precipitation seasonality. (** $p < 0.01$).

Moreover, relationships between soil nutrients and climatic factors in the five main forest types were also observed. In Table 3, p (*, **) value represents whether climatic factors are correlated with soil nutrient contents, so as to determine whether there is statistical significance. The r value indicated the correlation between climate factors and soil nutrient contents. MAT was significantly and positively correlated with nutrients in PL, PB, and MLB, except for SOC in PB. TS had no effect on almost all nutrients but positively correlated with SOC in PB. MAP was similar to MAT in PL, PB, and MLB; in addition, MAP was also significantly correlated with TN, TK, TP, AK, AP in PP and TN, TP in PQ. Although the correlation between PS and nutrients was unimpressive compared with MAT and MAP in five forest types, it was negatively correlated with SOC in PL, TN, TP and TK in MLB, as well as SOC and AK in PP.

Table 3. Pearson correlations (r) between soil nutrients and climatic factors in the five main forest types.

Types	Nutrient	MAT	TS	MAP	PS	Types	Nutrient	MAT	TS	MAP	PS
PL	SOC	0.287 **	0.130	0.543 **	−0.235 *	PB	SOC	0.188	0.261 *	0.542 **	−0.223
	TN	0.380 **	0.010	0.603 **	−0.140		TN	0.364 **	0.176	0.600 **	−0.148
	TK	0.376 **	0.030	0.579 **	−0.142		TK	0.387 **	0.191	0.586 **	−0.165
	TP	0.349 **	0.040	0.614 **	−0.173		TP	0.284 *	0.235	0.609 **	−0.222
	AK	0.379 **	0.058	0.586 **	−0.172		AK	0.345 **	0.227	0.550 **	−0.173
	AP	0.485 **	−0.06	0.542 **	−0.061		AP	0.365 **	0.204	0.519 **	−0.154
MLB	SOC	0.362 *	0.151	0.358 *	−0.274	PQ	SOC	0.199	0.301	0.322	−0.271
	TN	0.46 **	0.151	0.455 **	−0.337 *		TN	0.295	0.202	0.426 *	−0.215
	TK	0.546 **	0.157	0.407 *	−0.316		TK	0.121	0.047	0.201	0.059
	TP	0.549 **	0.197	0.434 **	−0.384 *		TP	0.141	0.383	0.454 *	−0.332
	AK	0.537 **	0.188	0.418 *	−0.349 *		AK	0.219	0.171	0.219	−0.128
	AP	0.556 **	0.060	0.437 **	−0.246		AP	0.168	0.329	0.337	−0.227
PP	SOC	0.309	0.126	0.360	−0.470 *	PP	SOC	0.309	0.126	0.360	−0.470 *
	TN	0.206	0.069	0.629 **	−0.453		TN	0.206	0.069	0.629 **	−0.453
	TK	0.270	0.044	0.614 **	−0.336		TK	0.270	0.044	0.614 **	−0.336
	TP	0.176	0.088	0.621 **	−0.436		TP	0.176	0.088	0.621 **	−0.436
	AK	0.273	0.056	0.619 **	−0.485 *		AK	0.273	0.056	0.619 **	−0.485 *
	AP	0.205	0.028	0.611 **	−0.464		AP	0.205	0.028	0.611 **	−0.464

SOC = soil organic carbon, TN = total nitrogen, TP = total phosphorus, TK = total potassium, AP = available phosphorus, and AK = available potassium. MAT = mean annual temperature, TS = temperature seasonality, MAP = mean annual precipitation, and PS = precipitation seasonality. PL = pure *Larix gmelinii* (Rupr.) Kuzen forest, PB = pure *Betula platyphylla* Suk. Forest, MLB = *Larix gmelinii* (Rupr.) Kuzen and *Betula platyphylla* Suk. mixed forest, PQ = pure *Quercus mongolica* Fisch. ex Ledeb. forest, PP = pure *Pinus sylvestris* L. var. *mongolica* Litv. Forest. (* $p < 0.05$; ** $p < 0.01$).

3.4. Stepwise Regressions between Climatic Factors and Soil Nutrients

Step regression between soil nutrients and climatic factors in the five main forest types is shown in Table 4. In the case of PB, the four climatic factors could affect all the six soil nutrients, and MAP was the first parameter entered into the model. In the case of MLB and PP, MAP and MAT were the key factors for influencing the five soil nutrients (TN, TP, TK, AP and AK). For PL, MAT, MAP and TS mainly affected SOC, TN, TP, TK and AK. However, for PQ, MAP was the key factor for TN and TP, and no parameters were entered into the model of SOC, TK, AP and AK. In all, we found that there were different influencing factors in various forest types.

Table 4. Step regressions between soil nutrients and climatic factors in the five main forest types.

Forest Types	Soil Nutrients	R	R ²	Adjusted R ²	Standard Error of the Estimate
PL	SOC	0.715	0.512	0.488	0.45880
	TN	0.741	0.549	0.539	0.19099
	TP	0.734	0.538	0.527	0.10257
	TK	0.717	0.513	0.502	0.21375
	AP	0.759	0.576	0.566	0.08648
	AK	0.726	0.527	0.516	2.61645
PB	SOC	0.762	0.580	0.552	0.50973
	TN	0.852	0.727	0.708	0.16591
	TP	0.829	0.687	0.665	0.10871
	TK	0.853	0.728	0.709	0.17232
	AP	0.812	0.660	0.637	0.08950
	AK	0.844	0.713	0.694	2.29320
MLB	SOC	0.606	0.367	0.307	0.60923
	TN	0.803	0.644	0.611	0.17465
	TP	0.809	0.654	0.621	0.09086
	TK	0.767	0.588	0.550	0.20503
	AP	0.740	0.548	0.520	0.09897
	AK	0.784	0.614	0.578	2.40780
PQ	SOC	–	–	–	–
	TN	0.782	0.612	0.557	0.15610
	TP	0.454	0.206	0.172	0.16556
	TK	–	–	–	–
	AP	–	–	–	–
	AK	–	–	–	–
PP	SOC	0.470	0.221	0.172	0.50111
	TN	0.787	0.619	0.569	0.16243
	TP	0.759	0.576	0.520	0.08790
	TK	0.817	0.667	0.520	0.16327
	AP	0.768	0.590	0.535	0.10037
	AK	0.822	0.676	0.633	2.13592

Note: SOC = soil organic carbon, TN = total nitrogen, TP = total phosphorus, TK = total potassium, AP = available phosphorus, and AK = available potassium. PL = pure *Larix gmelinii* (Rupr.) Kuzen forest, PB = pure *Betula platyphylla* Suk. Forest, MLB = *Larix gmelinii* (Rupr.) Kuzen and *Betula platyphylla* Suk. mixed forest, PQ = pure *Quercus mongolica* Fisch. ex Ledeb. forest, PP = pure *Pinus sylvestris* L. var. *mongolica* Litv. Forest, “–” = there is no value.

4. Discussion

4.1. Forest Types Influence Soil Nutrient Contents

The relationships between soil nutrients and forest types have been presented previously [3]. In addition, northeastern China has been considered as one of the regions with the most abundant soil nutrition [16,33]. To confirm the influencing trends of the variation of soil nutrient contents to forest types, PCA was carried out on the collected data. From the distribution of the loading plot in the PCA space, it was found that the forest type influenced the soil nutrients. For instance, SOC, TP, TN, AK, AP and TK were higher in PL, PB, MLB and PP in this study, while these soil nutrients showed the opposite trend. So, we suspect that there were certain correlations between soil nutrients and forest type. In addition, the differences caused by vegetation effects in the responses of the nutrients may be due to slight distinctions in parent material in different forest types [34,35].

From the above results, it was found that the distributions of soil nutrients from different forests were different. These values were influenced by the forest site conditions, advantageous tree species and different amounts of forest litter as well as the composition and decomposition levels, so the differences in the forest soil nutrients are very obvious. For instance, the distribution of SOC was ranged in order PL > MLB > PB > PP > PQ with the SOC average content being 28.68, 28.46, 28.43, 28.28 and 26.68 g·kg⁻¹ respectively. From the viewpoint of succession, PL, MLB and PP were in the top stage of succession—the complexity of the tree species composition increased the possibilities of the accumulation of organic matter [36]—but PB and PQ were the secondary forests which were

disturbed more frequently in recent years. So, the SOC content of PL, MLB and PP should be larger than that of PB or PQ [37]. However, the SOC content in PP was minimal, even lower than in PB. This phenomenon was unexpected, and it is possible that it is related to the terrain: the slope is large, litter does not accumulate as much, and in addition to the soil acidity, the litter layer was difficult to decompose; therefore, the conditions are not conducive to the formation of organic matter, which means that the SOC content is low [3]. This also means that SOC stock will continue to increase if the interference is ended and the forest is developed toward the climax community; otherwise, the forest can turn into PQ and the stock of SOC will decrease, especially in the rich PB forest region.

Statistically, the distributions of TN and SOC were identical. A large number of data analysis results show that the TN was positively correlated with SOC. The order was PL > MLB > PB > PP > PQ with the contents being 4.2, 4.12, 4.11, 4.02 and 3.50 g·kg⁻¹ respectively. The distribution of TN identified in this study was in accordance with that presented by Zu et al. [16] and Jiang et al. [14]. The order of the TP content was PP > PL = MLB > PB > PQ and the contents were 1.81, 1.76, 1.76, 1.70 and 1.35 g·kg⁻¹ respectively. The correlations of the AP and SOC were identical but opposite to that of TP. The same phenomenon appeared with AK and TK, and this could be explained by the composition of TP and TK, which is very complex, with the existence of inorganic and organic states, and AP and AK being only part of them. This trend may have been due to the influence of various factors such as the climate. In addition, although AP content decreased with the MAP and MAT increasing, TP content increased [32,33]. This confirms that the vegetation type is a key factor that affects the soil nutrients of the Daxing'an Mountains ecosystems.

4.2. Soil Nutrient Responses to Climatic Factors

The study of Harradine, F. et al. indicated that climate (especially precipitation and temperature) has significant effects on pedogenesis and macronutrient cycling in soil [38]. It is a challenge to isolate each of the individual soil forming factors such as climate, vegetation, parent material and so on, due to the frequent co-variance of many factors [39]. For instance, changes in species vary with the climate and location. In the present paper, with the primary focus on the links between ecosystems and climate change, gradients of natural climate are noteworthy in studying the interactions between climate and variation in forest ecosystem processes.

On the whole, it was found that SOC decreased with increasing MAT, and SOC increased with increasing MAP (Table 1). This trend may be due to the hydrothermal conditions of Daxing'an Mountains area. The MAT in Daxing'an Mountains is −3.69 °C and the MAP is 481.2 mm. The region is rich in forest resources, and rainfall is abundant which is conducive to the growth of plants, while the low temperature is beneficial to the accumulation of biomass. Yimer, F. et al. suggested that some other factors, such as erosion, leaching of cations and variations in biomass production may influence soil property [39]. Our results were consistent with previous research which showed that increasing temperature leads to the growth of microorganisms [40], thus increasing the decomposition rate of SOC [41,42]. Precipitation change will affect the content of plant-available water and the length of the growing season; a reduction in precipitation can limit plant growth [30], and the soil microbial number will surge after rain [43], thus reducing the SOC content in soil. In this study, a similar conclusion can be drawn.

More than half of the soil nutrients were significantly linked with variations in the climatic factors, but PQ had weak correlations between climatic factors and soil nutrients, showing that the soil nutrient distribution characteristics were affected by forest types. TN was affected by MAP, MAT and TS, while TP was susceptible to MAP in PQ (Table 3). However, MAT and MAP were the key factors for most soil nutrients in PB, PL, MLB and PP (Table 3), indicating that MAP and MAT played key roles in the accumulation of biomass matter in this region. In addition, the weak correlations between soil nutrients and the climatic factors (PS, TS) indicated that the changes in temperature and precipitation affected the time scale of soil nutrients.

The wide distribution of the forested land resulted in the higher storage of soil nutrient elements in the Daxing'an Mountains area than in other areas of China, even though the contents vary between the different forest types. Although determining the mechanism through which climate acted on the forest types proved difficult, the spatial distribution of the soil nutrients was related to vegetation in the Daxing'an Mountains.

5. Conclusions

The results of this study revealed obvious differences in the variation of soil nutrients. The content of each nutrient in PP was minimal, in obvious contrast to other forest types. Correlations between the soil nutrients and climatic factors were found in this paper. Climatic factors could affect soil nutrients in different forest types. We confirmed that climatic factors (MAT and MAP) are instrumental in affecting soil nutrients (SOC, TN, TP, TK, AP and AK) in five main forest types in the Daxing'an Mountains. Identifying the relationships between soil nutrients, climatic factors and forest types, as suggested in this research, can provide theoretical foundations to further comprehend nutrient cycling in the forest ecosystem.

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