



Article

Effects of Different Ecological Restoration Pattern on Soil Organic Nitrogen Components in Alpine Sandy Land

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Abstract: Ecological restoration can improve soil fertility and have a significant impact on the soil nitrogen cycle. Nitrogen (N) is an essential nutrient element for plant growth and development, and also an important factor limiting soil productivity. As an important part of soil nitrogen, the composition and proportion of soil organic nitrogen components can directly or indirectly affect the difficulty of soil organic nitrogen mineralization and nitrogen availability, and then affect soil fertility. However, the current studies on soil nitrogen under ecological restoration mainly focus on nitrogen accumulation and nitrogen mineralization, while there are relatively few studies on changes in soil organic nitrogen components, especially in alpine regions. Therefore, in this study, three restoration pattern of mixed forage (MG), single shrub (SA) and shrub combination (SG) that have been restored continuously for 15 years in northwest Sichuan, China, were taken as the research object, and natural sandy land (CK) without manual intervention was taken as the control. Through field sampling and laboratory analysis, the characteristics of the soil nitrogen content and its proportion to soil total nitrogen (TN) under ecological restoration in alpine sandy land in northwest Sichuan, China, were investigated, and the correlation between the nitrogen content and soil physicochemical properties was analyzed. The results showed that the three ecological restoration patterns significantly increased the contents of acylated ammonium nitrogen (AMMN), acid-lyzed amino sugar nitrogen (ASN), acid-lyzed amino acid nitrogen (AAN), acid-lyzed unknown nitrogen (HUN), acid-lyzed total nitrogen (AHN) and non-acid-lyzed nitrogen (NHN) in soil, and the change trend was consistent with that of soil TN. Ecological restoration improved soil nitrogen mineralization and storage capacity by increasing the proportion of AAN, HUN and NHN to soil TN, and the effect was most obvious in the MG pattern 20–40 cm and SG pattern 40–60 cm soil layers. In general, except ASN, the soil nitrogen content was positively correlated with the soil TN, soil water content (SWC) and soil organic carbon (SOC), and negatively correlated with the soil bulk density (BD) and pH. The results of this study will help us to understand the supply capacity of soil nitrogen under ecological restoration and provide a scientific basis for the selection of an ecological restoration mode and the improvement of the restoration effect and efficiency in alpine sandy land.

Keywords: alpine sandy land; ecological restoration; soil organic nitrogen

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1. Introduction

The alpine grassland in Northwest Sichuan, China, is the largest plateau peat swamp wetland in the world and one of the key areas of biodiversity in China [1,2]. However, due to the influence of natural and human factors over a long time period, the alpine grassland in this area has been seriously degraded, and desertification has occurred locally [3]. Ecological restoration can enhance the surface soil fertility of grassland and improve grassland productivity, which is the most direct and effective management measure to

restore degraded grassland [4,5]. In the process of ecological restoration, shrubs and grasses suitable for the growth and control of sand have the functions of preventing wind and fixing sand, improving soil, improving local microenvironment, promoting the recovery of surface vegetation and gradually forming a stable shrub and grass ecosystem [6]. The stability and development of the shrub and grass ecosystem play an important role in the restoration of sandy land [7,8]. Nitrogen is one of the essential elements for plant growth [9,10], and is an important basis for soil fertility [11,12]. Studies have shown that ecological restoration can have a significant impact on soil nitrogen and other nutrient cycling [13], and the grassland ecosystem is increasingly restricted by nitrogen [14]. Therefore, the study of soil nitrogen supply under the condition of ecological restoration is helpful for providing a scientific basis for the selection of an ecological restoration mode and the improvement of the restoration effect in Alpine sandy land.

Soil organic nitrogen is the source and reservoir of soil mineral nitrogen. Its chemical form and occurrence status are the key factors affecting the availability of soil nitrogen, which determines the supply and storage capacity of soil nitrogen [15,16]. In order to deal with the problem of grassland desertification, researchers have taken restoration measures such as fencing [17], the construction of artificial grassland [18], afforestation [19], returning farmland to forest [20] and so on, which can increase the coverage of surface vegetation and reduce water and soil loss [13,21]. At the same time, the growth and development of plants, litter death and decomposition will affect the development of soil, and change the content and distribution of soil nitrogen components [22,23]. Current studies suggest that ecological restoration will significantly increase or reduce the content of soil organic nitrogen, and the effects of different ecological restoration patterns are different. Du et al. [24] found that in the 4–8 years of the enclosure of degraded grassland, the content of acylated ammonium nitrogen in the 0–30 cm topsoil increased significantly. Liu et al. [25] found that the soil microbial biomass nitrogen content in the 38-year-old *Robinia pseudoacacia* plantation was significantly higher than that in the 15-year-old *Robinia pseudoacacia* plantation in the typical vegetation restoration area of the Loess Plateau in China. Wang et al. [26] studied the soil total nitrogen storage under different land use patterns in the ecological restoration area of the hilly region of North China; the results showed that compared with cropland, the soil total nitrogen content in stock shrub is 10.8% higher, and in forestland, is 39.8% higher. With the increase in biochar application rate, the contents of soil acid-lyzed total nitrogen, acylated ammonium nitrogen and acid-lyzed amino acid nitrogen increased significantly. At present, scholars are carrying out research on Ecological Restoration in alpine regions. Chen et al. [27] found that the surface vegetation can be restored quickly after fencing the severely wind eroded sandy grassland, which promotes the accumulation of soil nitrogen content. Jin et al. [28] studied the physicochemical properties of soil under different ecological restoration measures in Alpine mining areas in Qinghai Province, and found that the soil nitrogen content increased significantly under the restoration pattern of *Elymus nutans*, *Poa pratensis* and other tree species. However, the research on the soil nitrogen under ecological restoration mainly focuses on nitrogen accumulation and nitrogen mineralization [29,30]; focus on the changes of soil organic nitrogen components is relatively less, especially in alpine regions.

The alpine grassland in Northwest Sichuan, China, has an extremely important ecological environment position. However, due to the influence of natural and human factors that have occurred for a long time, the alpine grassland in this area has been seriously degraded, and desertification has occurred locally. At present, the focus and hot spot of desertification control work are mainly concentrated in the arid and semi-arid areas of North China, while the attention and research on grassland desertification in the semi humid areas of South China are relatively less. Therefore, in this study, four ecological restoration patterns—mixed forage, single shrub, shrub combination and control—were selected as the subjects of investigation. The soil chemical analysis method was used to determine the content and proportion of soil organic nitrogen components under different ecological restoration patterns in order to explore the effect of different ecological restora-

tion patterns on soil nitrogen components. The objectives of this study are as follows: (1) to study the changes of soil nitrogen components under different ecological restoration patterns; (2) to study the changes in soil nitrogen components in the proportion of soil total nitrogen under different ecological restoration patterns; (3) to explore the relationship between soil organic nitrogen components and basic physicochemical properties. This study can reveal the soil nitrogen availability, supply capacity and its influencing factors under the ecological restoration of Alpine sandy land in Northwest Sichuan, China, and provide a scientific basis for the selection of ecological restoration patterns of Alpine sandy land and the improvement of the restoration effect and efficiency.

2. Materials and Methods

2.1. Study Area Description

The study area is located in Wache Township, Hongyuan County, Aba Tibetan and Qiang Autonomous Prefecture, Sichuan Province, with geographic coordinates ranging from 31°51′–33°19′ north latitude and 101°51′–103°23′ east longitude. The terrain inclines from southeast to northwest, with an altitude of 3210–4857 m. The climate belongs to continental plateau cold temperate monsoon climate, with short spring and autumn, long winter and no summer. The average annual rainfall is 791.95 mm. The rainfall is mainly between May and October. The average annual temperature is 1.1 °C, the average temperature of the coldest month is −10.3 °C, the average temperature of the hottest month is 10.9 °C, the extreme minimum temperature is −36 °C and the average annual snow period is 76 days, without an absolute frost-free period. The sunshine is sufficient and the solar radiation is strong. The average annual sunshine duration is 2158.7 h, and the annual total solar radiation is 6194 MJ/m². The main soil types in the area are meadow soil, swamp soil and peat soil. Due to the long-term impact of human factors, such as population increase and overgrazing, as well as the impact of natural factors, such as global warming and damage by rats and insects, the alpine grassland in Northwest Sichuan, China, has been seriously degraded, and desertification has occurred in some areas [31,32]. *Salix cupularis* belongs to *Salicaceae* shrub, which can grow in alpine semi-arid environments, can resist wind erosion, fix sand, retain water and increase plant diversity [33]. Since the 1980s, with the support of relevant funds from Sichuan Province and the Ministry of science and technology of the People's Republic of China, the demonstration area has carried out the restoration mode based on planting shrubs and sowing forages, and formed three typical ecological restoration patterns based on the combination of fence enclosure and sand barrier and mixed forage; fence enclosure and sand barrier and single shrub; and fence enclosure and sand barrier and shrub grass for 14 years. The pattern of enclosure and sand barrier and mixed forage is to adopt a wire fence enclosure and grazing prohibition for semi-fixed sandy land, and set up plant sand barriers around it to prevent wind and fix sand. At the same time, Perennial Forages such as *Elymus nutans*, *Festuca arundinacea* and *Elymus sibiricus* are artificially replanted. The pattern of enclosure and sand barrier and *Salix cupularis* shrub is that under the pattern of enclosure and sand barrier, *Salix cupularis* is cut into strips with a plant spacing of 1–2 m and a row spacing of 2.5 m, without artificial supplementary seeding. The combination pattern of enclosure and sand barrier and shrub grass is to cut *Salix cupularis* and artificially mix perennial forage under the pattern of enclosure and sand barrier.

2.2. Experimental Design

In the middle of August 2021, three ecological restoration patterns test areas were selected in the Northwest Sichuan, China, alpine sandy land ecological management demonstration area base, including fencing and sand barrier and mixed forage (MG), fencing and sand barrier and single shrub (SA) and fencing and sand barrier and shrub combination (SG), with the adjacent natural sandy land (CK) without artificial intervention as the control sample. In the above three test areas, 25 m with basically the same site conditions were selected, respectively, ×25 m sample plot, and the distance between the

sample plot and the boundary in the test area is more than 100 m. In the two experimental areas of mixed forage (MG) and natural sandy land (SA), four representative 1 m × 1 m quadrats as repetition. In the two experimental areas of single shrub (SA) and shrub combination (SG), four representative 1 m × 1 m small quadrats are used as repetition (the basic physicochemical properties of soil in the sample plot is shown in Table 1).

Table 1. Effects of ecological restoration model on soil basic physicochemical properties.

Depth of Soil (cm)	Treatment	SWC (%)	BD (g/cm ³)	pH	SOC (g/kg)	TN (g/kg)
0–20	natural sandy land (CK)	6.41 ± 0.89 c	1.40 ± 0.02 a	6.86 ± 0.07 a	2.32 ± 0.77 c	0.24 ± 0.01 d
	mixed forage (MG)	10.20 ± 0.58 a	1.33 ± 0.05 a	6.37 ± 0.06 b	6.04 ± 0.93 a	0.66 ± 0.01 b
	single shrub (SA)	8.21 ± 1.44 b	1.38 ± 0.08 a	6.33 ± 0.17 b	4.13 ± 1.16 b	0.33 ± 0.02 c
	shrub combination (SG)	9.72 ± 1.05 ab	1.39 ± 0.06 a	6.74 ± 0.03 a	5.90 ± 1.42 a	0.69 ± 0.01 a
20–40	natural sandy land (CK)	6.99 ± 0.51 b	1.43 ± 0.04 a	6.91 ± 0.05 a	2.47 ± 0.36 c	0.20 ± 0.01 d
	mixed forage (MG)	9.37 ± 1.56 ab	1.26 ± 0.12 b	6.29 ± 0.10 c	10.13 ± 2.53 a	1.28 ± 0.09 a
	single shrub (SA)	11.21 ± 3.39 a	1.43 ± 0.06 a	6.01 ± 0.19 d	3.39 ± 0.52 bc	0.34 ± 0.02 c
	shrub combination (SG)	11.43 ± 2.21 a	1.34 ± 0.02 ab	6.65 ± 0.14 b	5.06 ± 0.78 b	0.63 ± 0.01 b
40–60	natural sandy land (CK)	9.72 ± 2.91 b	1.42 ± 0.06 a	6.81 ± 0.05 a	1.81 ± 0.40 d	0.17 ± 0.01 d
	mixed forage (MG)	10.67 ± 1.68 b	1.37 ± 0.05 ab	6.26 ± 0.10 b	5.70 ± 0.56 b	0.62 ± 0.01 b
	single shrub (SA)	14.80 ± 1.35 a	1.41 ± 0.07 ab	6.15 ± 0.20 b	3.32 ± 1.00 c	0.42 ± 0.01 c
	shrub combination (SG)	15.00 ± 3.93 a	1.30 ± 0.09 b	6.34 ± 0.19 b	8.34 ± 0.45 a	1.15 ± 0.02 a

Different lowercase letters indicated significant differences among treatments at $p < 0.05$, the same below.

2.3. Measurement Parameters

At 1 m × 1 m, the small sample square of 1 m, soil samples of 0–20 cm, 20–40 cm and 40–60 cm soil layers were collected, respectively. Three samples were taken from each layer and mixed evenly and bagged. At the same time, the ring knife, the volume of which is 100 cm³, was used to sample 0–10 cm of soil in the sample plot. After that, they were put into plastic bags and taken back to the laboratory. Plant residues, roots and visible soil animals (such as earthworms) were removed from the returned samples, then the samples were weighted using an electronic balance with an accuracy of 0.1 g. The wet weight of the soil was recorded after removing the weight of the ring knife. The dry weight of the soil was recorded after it was put into a constant temperature drying oven and dried it to constant weight at 105 °C. The wet weight and the dry weight of the soil were used to calculate the soil bulk density and soil water content.

The basic physicochemical properties of soil include soil water content (SWC), bulk density (BD), pH value, soil organic carbon (SOC) and soil total nitrogen (TN). The soil water content and the bulk density can be calculated as follows [34]:

$$SWC = \frac{m_1 - m_2}{m_1} \times 100\% \quad (1)$$

where SWC: soil water content; m_1 : the wet weight of the soil, g; m_2 : the dry weight of the soil, g.

$$BD = \frac{m_2}{(1 - SWC)V} \quad (2)$$

where BD: bulk density; m_2 : the dry weight of the soil, g; SWC: soil water content; V: the volume of the collector for the soil, m³.

The soil pH value was determined using a pH meter (soil:water = 1:2.5) [35], and the soil organic carbon content was determined using the high temperature external heat potassium dichromate oxidation volumetric method [34]. Soil organic nitrogen component indexes include acid-lyzed total nitrogen (AHN), acylated ammonium nitrogen (AMMN), acid-lyzed amino acid nitrogen (AAN), acid-lyzed amino sugar nitrogen (ASN), acid-lyzed unknown nitrogen (HUN) and non-acid-lyzed nitrogen (NHN), which were determined using the acid hydrolysis distillation method [36]. The content of AHN was determined using

the H_2SO_4 mixed catalyst distillation method, the content of AMMN was determined using the MgO distillation method, the content of AAN was determined using the Ninhydrin distillation method, the content of ASN was determined using the phosphate borate buffer distillation method and the content of HUN was the content of AHN minus the content of AMMN, AAN and HUN; the NHN content is soil TN content minus AHN content [37].

2.4. Statistical Analysis of Data

All data were processed using Microsoft Excel 2022 for statistical calculations, data listing and graph plotting. SPSS 26.0 and R 4.2.1 were used for data analysis. One way ANOVA was used for comparison of index differences and the LSD (least significant difference) method was used for checking the significance of index differences. Linear regression analysis was used to study the correlation between soil organic nitrogen components and basic physicochemical properties, and the determination coefficient (R^2) and significance ($p < 0.05$) were used to evaluate the fitting effect.

3. Results

3.1. Effects of Different Ecological Restoration Pattern on AHN and NHN Content

The results showed that the content of AHN in the soil increased significantly at different soil depths of the three ecological restoration patterns (Figure 1a). The restoration pattern of MG increased the most in the 20–40 cm soil layer, while the restoration pattern of SG increased the most in the 0–20 cm and 40–60 cm soil layers. Compared with CK, the three ecological restoration patterns significantly increased: 205.52 mg/kg, 22.88 mg/kg and 300.91 mg/kg in 0–20 cm soil layer, respectively ($p < 0.05$); in the 20–40 cm soil layer, 767.44 mg/kg, 102.68 mg/kg and 325.33 mg/kg were significantly increased, respectively ($p < 0.05$); in the 40–60 cm soil layer, 293.37 mg/kg, 159.10 mg/kg and 685.66 mg/kg were significantly increased ($p < 0.05$). In general, the soil NHN content increased significantly at different soil depths of the three ecological restoration patterns (Figure 1b). In the 0–20 cm and 20–40 cm soil layers, the restoration pattern of MG increased the most, while in the 40–60 cm soil layer, the restoration pattern of SG increased the most. Compared with CK, the restoration pattern of MG, SA and SG in the 0–20 cm soil layer increased significantly by 208.73 mg/kg, 60.55 mg/kg and 145.81 mg/kg, respectively ($p < 0.05$); the restoration pattern of MG and SG in the 20–40 cm soil layer increased significantly, by 346.10 mg/kg and 109.10 mg/kg, respectively ($p < 0.05$), and there was no significant difference between the restoration pattern of SA and CK; in the 40–60 cm soil layer, the restoration pattern of MG, SA and SG increased significantly by 151.48 mg/kg, 92.84 mg/kg and 295.71 mg/kg, respectively ($p < 0.05$).

3.2. Effects of Different Ecological Restoration Pattern on Soil Organic Nitrogen Components Content

Compared with CK, the content of AMMN in the soil increased significantly at different soil depths of the three ecological restoration patterns (Figure 2a). The restoration pattern of MG increased the most in the 0–20 and 20–40 cm soil layers, while the restoration pattern of SG increased the most in the 40–60 cm soil layers. Compared with CK, the three ecological restoration patterns increased significantly by 67.64 mg/kg, 16.64 mg/kg and 74.13 mg/kg in the 0–20 cm soil layer, respectively ($p < 0.05$), and there was no significant difference in the restoration pattern of MG and SG; in the 20–40 cm soil layer, 201.51 mg/kg, 14.05 mg/kg and 77.66 mg/kg were significantly increased, respectively ($p < 0.05$); in the 40–60 cm soil layer, 84.93 mg/kg, 38.71 mg/kg and 157.68 mg/kg were significantly increased, respectively ($p < 0.05$).

Compared with CK, the content of AAN in the soil increased significantly at different soil depths of the three ecological restoration patterns (Figure 2b). The restoration pattern of MG increased the most in the 0–20 cm and 20–40 cm soil layers, while the restoration pattern of SG increased the most in the 40–60 cm soil layers. Compared with CK, the three ecological restoration patterns increased significantly by 87.75 mg/kg, 34.86 mg/kg

and 84.12 mg/kg in the 0–20 cm soil layer, respectively ($p < 0.05$), and there was no significant difference in the restoration pattern of MG and SG; in the 20–40 cm soil layer, 202.11 mg/kg, 33.02 mg/kg and 80.87 mg/kg were significantly increased, respectively ($p < 0.05$); 84.72 mg/kg, 48.30 mg/kg and 119.85 mg/kg were significantly increased in the 40–60 cm soil layer, respectively ($p < 0.05$).

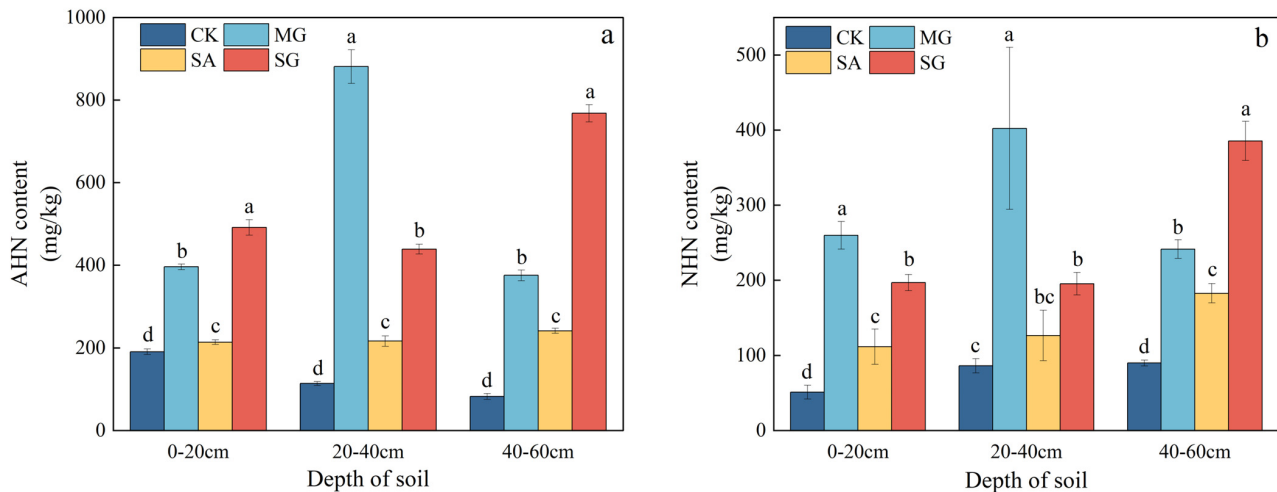


Figure 1. The content of acid-lyzed total nitrogen and non-acid-lyzed nitrogen in soil under different ecological restoration pattern. (a) Content of soil acid-lyzed total nitrogen under different ecological restoration pattern. (b) Content of soil non-acid-lyzed nitrogen under different ecological restoration pattern. Where there is an identical marking letter, the difference is not significant, and where there is a different marking letter, the difference is significant. Significant level: $p < 0.05$.

Compared with CK, the content of ASN in the soil increased significantly at different soil depths of the three ecological restoration patterns (Figure 2c), and only decreased significantly in the 0–20 cm soil layer under the restoration pattern of SA. In general, the restoration pattern of SG increased the most in the 20–40 cm soil layer, while the restoration pattern of SA increased the most in the 40–60 cm soil layer. Compared with CK, the restoration pattern of MG and SG in the 0–20 cm soil layer increased significantly, by 5.23 mg/kg and 5.63 mg/kg, respectively ($p < 0.05$), and the restoration pattern of SA decreased significantly by 13.67 mg/kg ($p < 0.05$); in the 20–40 cm soil layer, the restoration pattern of SA and SG increased significantly, by 7.65 mg/kg and 11.70 mg/kg, respectively ($p < 0.05$), and there was no significant difference between the restoration pattern of MG and CK; in the 40–60 cm soil layer, the restoration pattern of MG, SA and SG increased significantly, by 5.88 mg/kg, 25.69 mg/kg and 5.83 mg/kg, respectively ($p < 0.05$), and there was no significant difference in the restoration pattern of MG and SG.

Compared with CK, the content of HUN in the soil increased significantly at different soil depths of the three ecological restoration patterns (Figure 2d), and only decreased significantly in the restoration pattern of the SA 0–20 cm soil layer. The recovery pattern of MG increased the most in the 20–40 cm soil layer, while the recovery pattern of SG increased the most in the 0–20 cm and 40–60 cm soil layers. Compared with CK, in the 0–20 cm soil layer, the restoration pattern of MG and SG increased significantly, by 44.90 mg/kg and 137.04 mg/kg, respectively ($p < 0.05$), and the restoration pattern of SA decreased significantly by 14.95 mg/kg ($p < 0.05$); in the 20–40 cm soil layer, the restoration pattern of MG, SA and SG increased significantly, by 360.14 mg/kg, 47.97 mg/kg and 155.10 mg/kg, respectively ($p < 0.05$); in the 40–60 cm soil layer, the restoration pattern of MG, SA and SG increased significantly, by 117.83 mg/kg, 46.37 mg/kg and 402.31 mg/kg, respectively ($p < 0.05$).

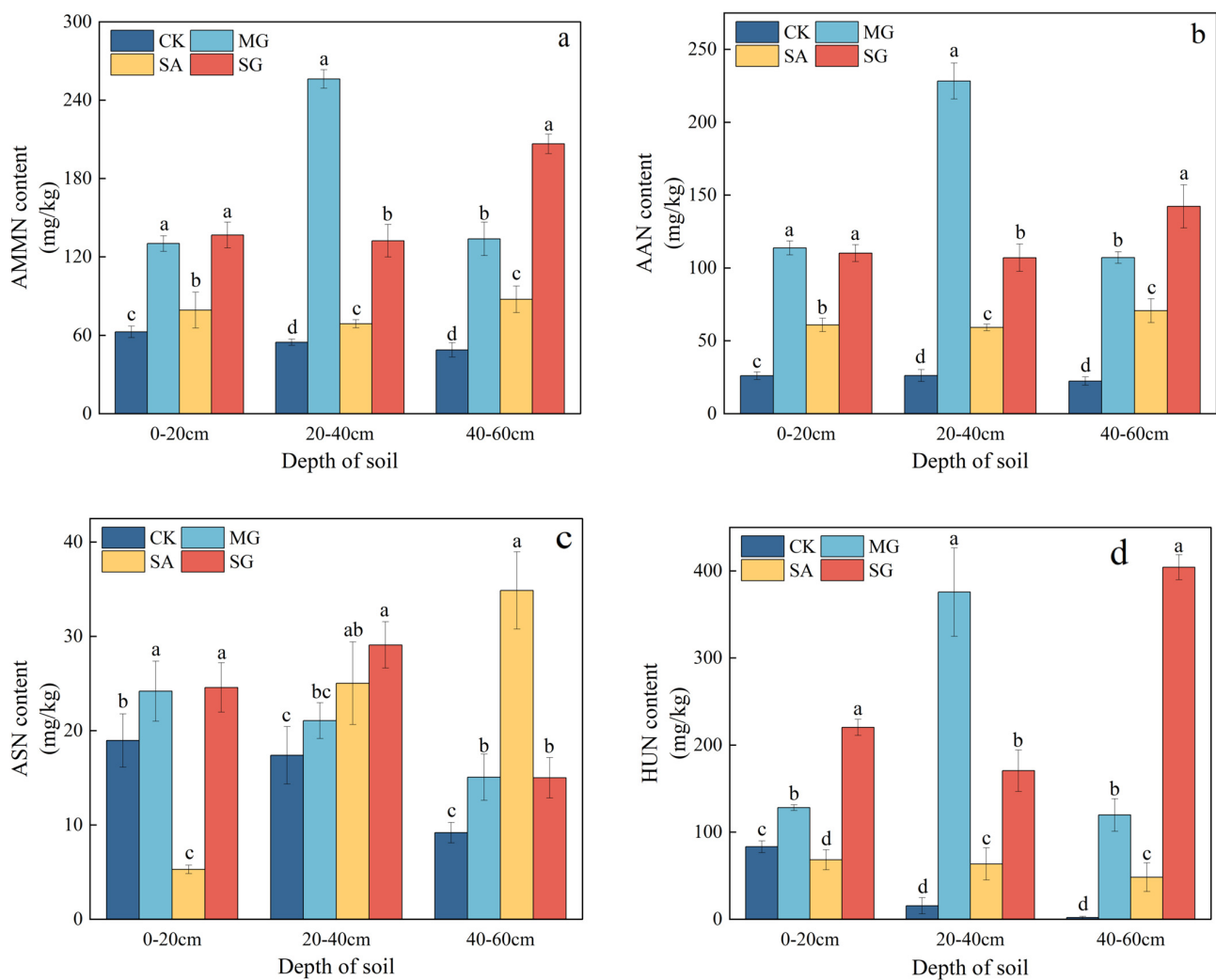


Figure 2. Content of soil nitrogen components under different ecological restoration pattern. (a) Content of soil acylated ammonium nitrogen under different ecological restoration pattern. (b) Content of soil acid-lyzed amino acid nitrogen under different ecological restoration pattern. (c) Content of soil acid-lyzed amino sugar nitrogen under different ecological restoration pattern. (d) Content of soil acid-lyzed unknown nitrogen under different ecological restoration pattern. Where there is an identical marking letter, the difference is not significant, and where there is a different marking letter, the difference is significant. Significant level: $p < 0.05$.

3.3. Effects of Different Ecological Restoration Pattern on the Proportion of Soil Organic Nitrogen Components in Soil TN

The results showed that the three ecological restoration patterns significantly changed the proportion of nitrogen components in the soil TN at different depths, among which HUN and NHN accounted for the largest proportion, and ASN accounted for the smallest proportion (Figure 3). In the 0–20 cm soil layer, the three ecological restoration patterns increased the proportion of NHN and AAN, but decreased the proportion of AMMN, ASN and HUN. In the 20–40 cm and 40–60 cm soil layers, the three ecological restoration patterns increased the proportions of AAN and HUN, but decreased the proportions of NHN, AMMN and ASN.

In the 0–20 cm soil layer, compared with CK, the proportion of NHN increased significantly by 18.51%, 13.03% and 7.54% under the restoration pattern of MG, SA and SG, respectively ($p < 0.05$). The proportion of AMMN was significantly reduced, by 6.03% and 6.04%, under the restoration patterns of MG and SG, respectively ($p < 0.05$), and there was no significant difference between the restoration patterns of SA and CK. Under the

restoration patterns of MG, SA and SG, the ASN ratio decreased significantly, by 4.16%, 6.21% and 4.27%, respectively ($p < 0.05$), and the restoration pattern of MG and SG had no significant difference. The AAN ratio increased significantly by 6.59%, 8.01% and 5.23% under the restoration patterns of MG, SA and SG, respectively ($p < 0.05$). The HUN ratio was significantly reduced by 14.91% and 13.38% under the restoration patterns of MG and SA, respectively ($p < 0.05$), and there was no significant difference between the restoration patterns of SG and CK.

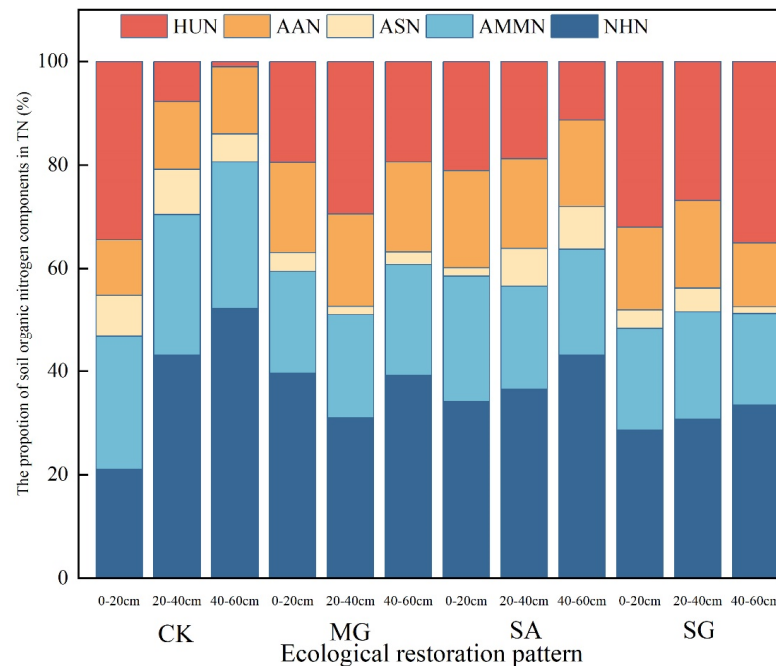


Figure 3. Effects of different ecological restoration pattern on the proportion of soil organic nitrogen components in soil TN.

In the 20–40 cm soil layer, compared with CK, the proportion of NHN was significantly reduced by 12.04% and 12.29% under the restoration patterns of MG and SG, respectively ($p < 0.05$), and there was no significant difference between the restoration patterns of SA and CK. The proportion of AMMN was significantly reduced by 7.30%, 7.28% and 6.59% under the restoration patterns of MG, SA and SG, respectively ($p < 0.05$), and there was no significant difference among the three ecological restoration patterns. The ASN ratio was significantly reduced by 7.08% and 4.14% under the restoration patterns of MG and SG, respectively ($p < 0.05$), and there was no significant difference between the restoration patterns of SA and CK. The proportion of AAN increased significantly by 4.76%, 4.24% and 3.84%, respectively ($p < 0.05$), under the restoration patterns of MG, SA and SG, and there was no significant difference among the three ecological restoration patterns. The proportion of HUN increased by 21.66%, 11.02% and 19.08% under the restoration patterns of MG, SA and SG, respectively.

In the 40–60 cm soil layer, compared with CK, the proportion of NHN under the restoration patterns of MG, SA and SG decreased significantly by 13.15%, 9.21% and 18.86%, respectively ($p < 0.05$). The proportion of AMMN was significantly reduced by 6.68%, 7.68% and 10.44% under the restoration patterns of MG, SA and SG, respectively ($p < 0.05$). The ASN ratio decreased significantly by 2.91% and 4.05% under the restoration patterns of MG and SG, respectively ($p < 0.05$), and SA increased significantly, by 2.90% ($p < 0.05$). The proportion of AAN increased significantly by 4.39% and 3.71% under the restoration patterns of MG and SA, respectively ($p < 0.05$). There was no significant difference between the restoration patterns of SG and CK. The proportion of HUN increased

significantly, by 18.35%, 10.29% and 33.99%, under the restoration patterns of MG, SA and SG, respectively ($p < 0.05$).

3.4. Relationship between Soil Organic Nitrogen Components and Soil Basic Physicochemical Properties

The results of the correlation analysis showed that soil TN was significantly positively correlated with AHN, NHN, AMMN, AAN and HUN ($p < 0.001$) (Figure 4); SWC was positively correlated with NHN, AHN, ASN and HUN ($p < 0.05$) (Figure 5); BD was negatively correlated with NHN, AHN, AMMN, AAN and HUN ($p < 0.05$) (Figure 6); pH was negatively correlated with NHN, AMMN and AAN ($p < 0.05$) (Figure 7); SOC was positively correlated with NHN, AHN, AMMN, AAN and HUN ($p < 0.05$) (Figure 8).

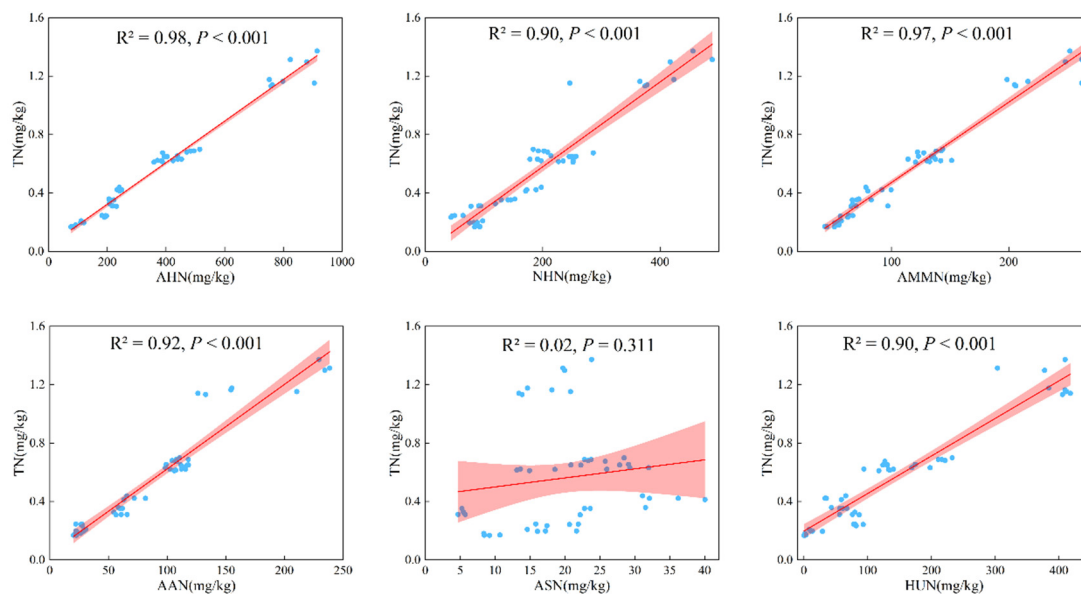


Figure 4. The relationship between soil nitrogen components and soil total nitrogen under different ecological restoration pattern.

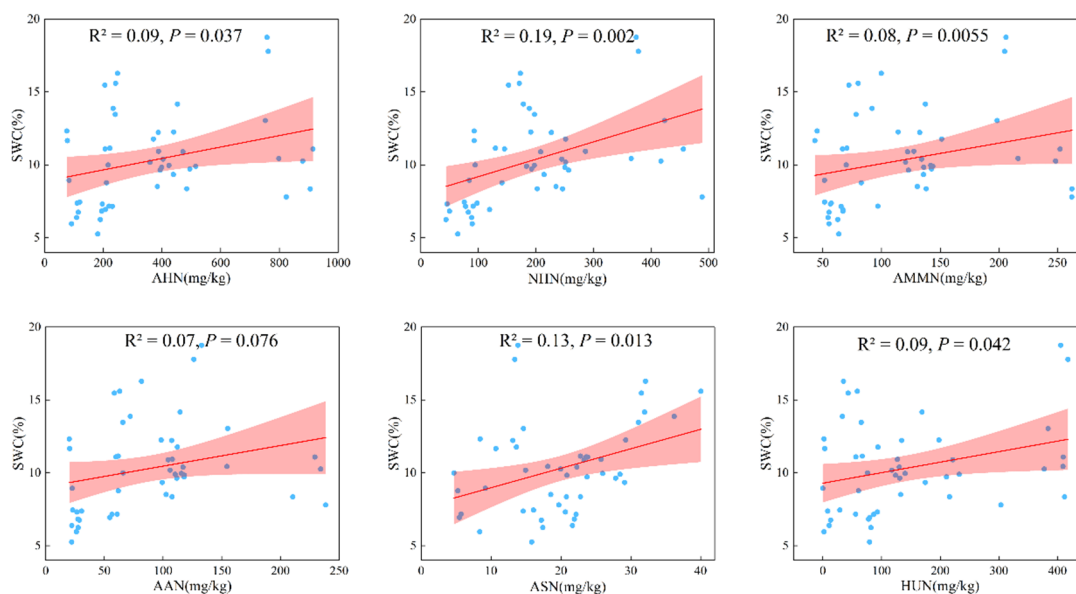


Figure 5. The relationship between soil nitrogen components and soil water content under different ecological restoration pattern.

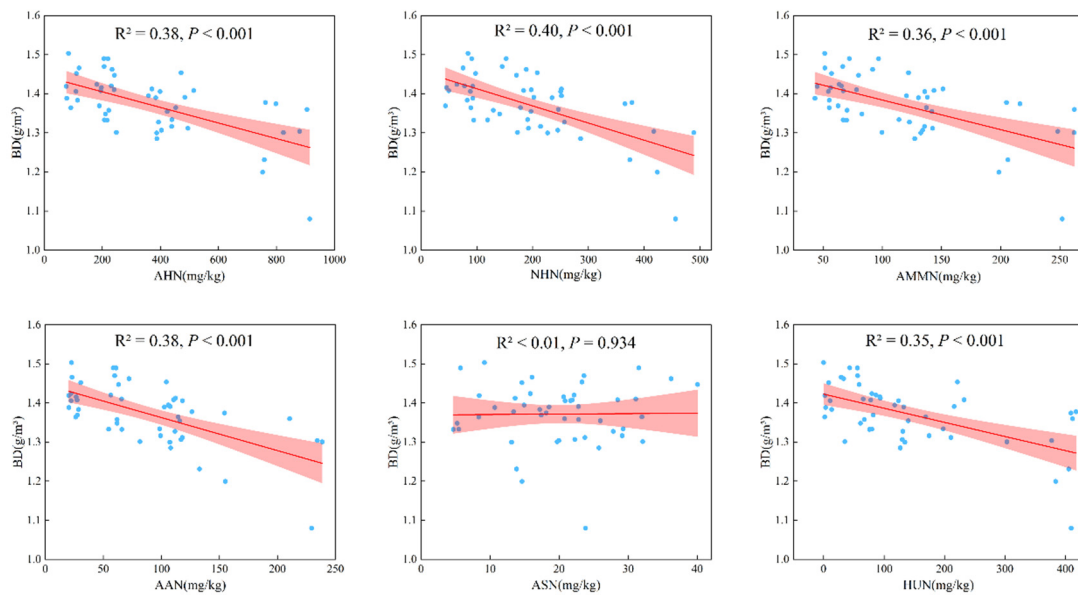


Figure 6. The relationship between soil nitrogen components and bulk density under different ecological restoration pattern.

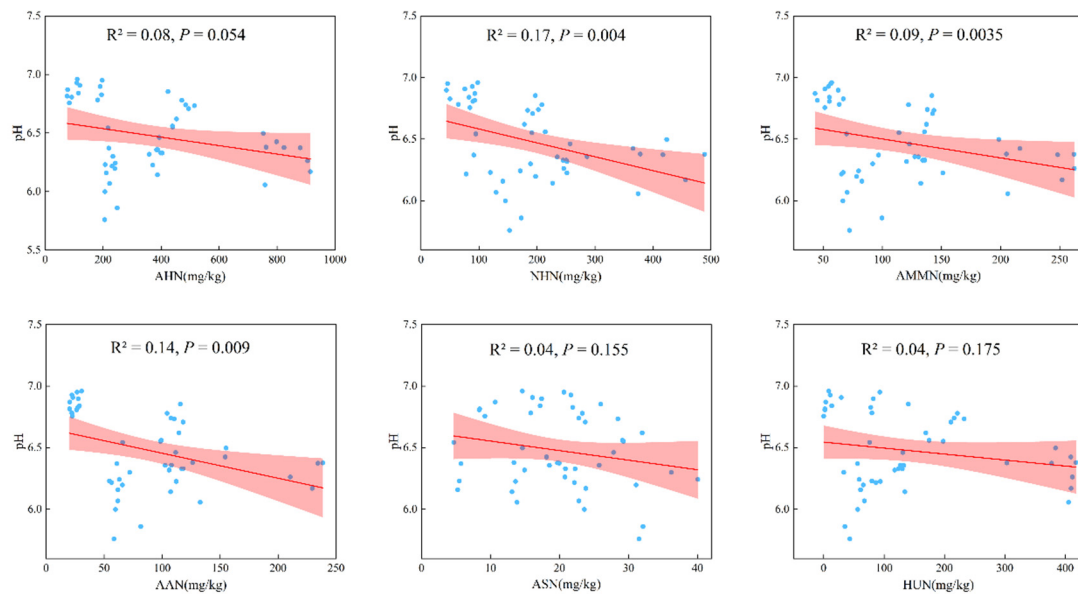


Figure 7. The relationship between soil nitrogen components and soil pH under different ecological restoration pattern.

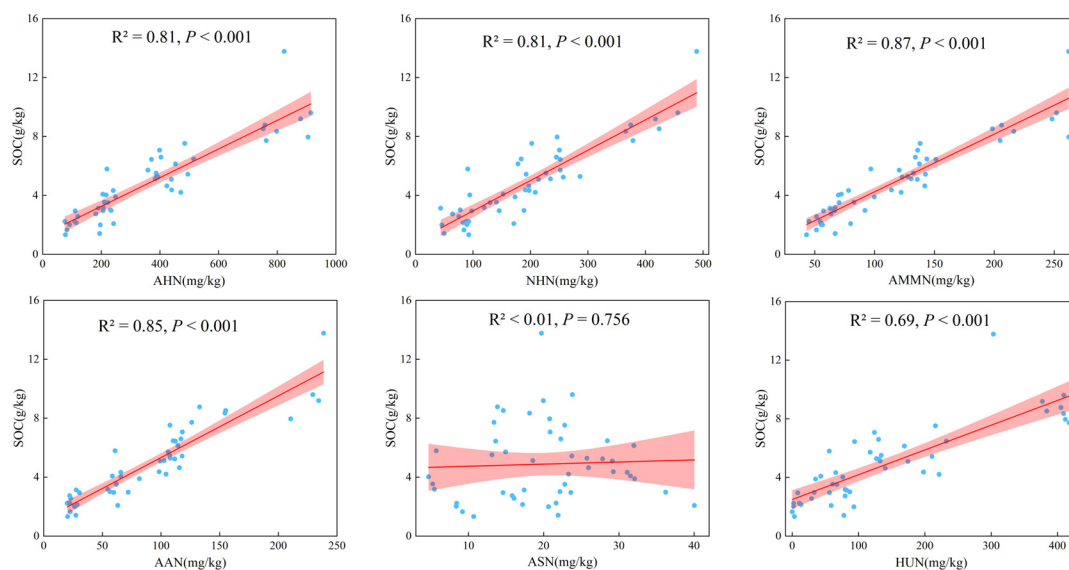


Figure 8. The relationship between soil nitrogen components and soil organic carbon under different ecological restoration pattern.

4. Discussion

4.1. Variation Trend of Soil Nitrogen Components Content under Different Ecological Restoration Pattern

The study showed that the three ecological restoration patterns significantly increased the contents of soil nitrogen components.

Ecological restoration significantly increased the content of soil AHN, which is consistent with the research results of Du et al. [24]. This is because the input of litter and root residues under ecological restoration increases the content of SOC, thus accelerating the transformation of soil inorganic nitrogen into organic nitrogen [38]. It also shows that ecological restoration improves the storage capacity of soil nitrogen and reduces the loss of nitrogen [26].

In this study, the changes in AAN and AMMN were consistent with that of AHN. The three ecological restoration patterns significantly increased the contents of soil AAN and AMMN, which indicated that the ecological restoration enhanced the soil nitrogen supply capacity.

Soil ASN is mainly derived from the microbial cell wall of soil microbial biosynthesis, which can reflect the nitrogen assimilation, absorption and utilization process of soil microorganisms, and is closely related to soil microbial activity, quantity and community structure [39,40]. He et al. [41] found that the content of soil amino sugar was closely related to the supply of soil carbon and nitrogen, and ASN played an indicator role in the microbial process of the soil carbon and nitrogen cycle. The study showed that the content of soil ASN increased with the deepening of the soil layer under the restoration pattern of SA, which was contrary to the change rule in the other restoration patterns. This may be because the soil microbial biomass is affected not only by the content of humus in the soil surface, but also by the root system of plants. Compared with the other ecological restoration patterns, the restoration pattern of SA has fewer understory herbaceous plants, so the microbial biomass is more affected by the root system of *Salix cupularis* shrub, resulting in stronger microbial activity and mineralization ability in the deep soil. Therefore, the soil ASN content increases with the deepening of the soil layer. It is worth noting that only the change in the soil ASN content in the soil nitrogen components is inconsistent with the change in the soil TN content, which is consistent with the research results of Wang et al. [42], and the linear fitting results also show this.

The results showed that the variation in soil HUN and NHN was similar to total nitrogen, and the three ecological restoration patterns significantly increased the contents of soil HUN and NHN, which could promote the accumulation of soil nitrogen.

4.2. Effects of Different Ecological Restoration Pattern on Soil Nitrogen Component

The results show that the three ecological restoration patterns can significantly improve the content of soil nitrogen components, but the content of soil nitrogen components and the proportion of soil TN under the restoration pattern of MG and SG are higher than those under the restoration pattern of SA. The reason for this may be that the restoration pattern of SA does not artificially plant new grass species, sparse sand plants are difficult to grow and reproduce rapidly and aboveground plant communities are difficult to build, so the coverage of aboveground plant communities in sandy land has not been significantly improved [43]; additionally, the rapid growth of *Salix cupularis* needs to absorb a large amount of soil nutrients and water, which makes a large amount of soil moisture and nutrients accumulate under shrubs, thus reducing the soil nutrients between shrubs, resulting in the lower content of soil nitrogen components in this pattern compared to the other two patterns. In addition, there are two reasons why the content of soil nitrogen components under the restoration pattern of SG is higher than that under the restoration pattern of SA. On one hand, it may be that the *Salix cupularis* under the restoration pattern of SG has higher coverage, height and biomass than that under the restoration pattern of SA, which has a higher sheltering effect on understory plants and promotes herbaceous plants to improve root nutrient utilization efficiency. On the other hand, it may be that there are more herbaceous plants and *Salix cupularis* roots under the restoration pattern of SG. In contrast, it may have a higher activation ability, leading to a higher soil nitrogen content than the SA pattern.

More importantly, the study also found that in the 20–40 cm soil layer of the MG pattern and the 40–60 cm soil layer of the SG pattern, except for soil ASN, the content of other soil nitrogen components was higher than that of the other soil layers under the same pattern; this may be because the soil layers in which the main roots gathered were different under the two patterns, which also showed that there was a consistent distribution pattern of soil nitrogen components among different soil layers under ecological restoration. However, this is different from the distribution characteristics of soil nitrogen in the different soil layers under different ecological restoration patterns in the arid and semi-arid areas of Northern China. Wang et al. [16] and Zhang et al. [44] studied the soil nitrogen content under different ecological restoration patterns in North China, and found that the soil nitrogen content decreased with the deepening of the soil layer. The reason for this may be that the ecological restoration in North China is more susceptible to temperature and humidity, which determine the growth and metabolism of soil microorganisms. The temperature and humidity of topsoil are more suitable for the growth of microorganisms, so the nitrogen content of topsoil is increased by decomposing litter. With the deepening of the soil layer, the soil nitrogen content decreased due to the reduction in microbial activity [45]. This also reflects that in North China, the increase in the soil nitrogen content caused by ecological restoration mainly depends on the decomposition of plant litter [26], which is different from the increase in soil nitrogen content caused by plant roots in semi-humid Northwest Sichuan, China. Furthermore, Hu et al. [46] studied the soil nitrogen content of the forest ecosystem in tropical South China under different ecological restoration modes, and found that the soil nitrogen content decreased with the deepening of the soil layer, which was not only consistent with the previous research on tropical forests [47], but also consistent with the research in North China. However, compared with the research in North China, the influencing factors of the soil nitrogen content are not only microbial activity, but also the absorption of plant roots, which is also the influencing factor of soil nitrogen content in Northwest Sichuan, China. With the increase in soil depth, due to the reduction in microbial decomposition activity and root absorption, the input of organic matter is limited, so the soil nitrogen content decreases with the increase in soil layer [47].

In conclusion, the soil nitrogen content has different trends with the increase in soil layer under different ecological restoration modes in temperate, subtropical and tropical regions, and the influencing factors of this phenomenon are also different.

4.3. Effects of Different Ecological Restoration Pattern on Soil Nitrogen Supply and Storage

AAN in soil organic nitrogen forms is a temporary nitrogen pool containing a large amount of mineralizable organic nitrogen in the soil plant system [48]. AMMN in soil organic nitrogen forms is the main source of available nitrogen absorbed by plants [49]. AAN and AMMN are the two most important organic nitrogen components that determine the potential of nitrogen mineralization [50]. The contents of AMMN and AAN are linearly correlated with the mineralization rate of mineralizable organic nitrogen, and are considered to be the main source of soil mineralizable organic nitrogen [51].

Soil NHN and HUN are closely related, which may be a molecular constituent of the quinine group as a bridge or a heterocyclic condensate in humus. They are stable components of soil nitrogen and are not easily mineralized. The increase in their distribution proportion has a negative impact on the ability of soil nitrogen supply [12,52].

The distribution ratio of difficult-to-mineralize nitrogen and easily-mineralized nitrogen will affect the rate of soil organic nitrogen mineralization and soil nitrogen storage capacity [53]. The results showed that ecological restoration increased the proportion of NHN and AAN in the 0–20 cm soil and the proportion of HUN and AAN in the 40–60 cm soil, indicating that three restoration patterns could simultaneously improve the supply and storage capacity of soil nitrogen.

It is worth noting that the contents of AHN, AMMN, AAN, HUN and NHN in the 20–40 cm soil layer of the restoration pattern of MG and the 40–60 cm soil layer of the restoration pattern of SG increased the most, and there was a generally significantly positive correlation between soil TN, SWC and SOC, and a negative correlation with soil pH and BD. This may be because the restoration pattern of MG and the restoration pattern of SG have higher root biomass. The restoration pattern of MG plant roots are relatively shallow and mainly located in the 20–40 cm soil layer, while the presence of *Salix cupularis* under the restoration pattern of SG leads to higher root biomass in the 40–60 cm soil layer, and *Salix cupularis* also has the characteristics of salt tolerance, which roots can reduce the soil pH of by secreting organic acids [54]. At the same time, the input of residue increases the content of SOC [55], and then increases the content of organic nitrogen and its components [38]. In addition, the correlation analysis results showed that the soil's easily-mineralized nitrogen components and the difficult-to-mineralize nitrogen components had significant correlation with the soil physicochemical properties. In general, the ecological restoration of Alpine sandy land in Northwest Sichuan, China, can significantly improve the supply and storage capacity of soil nitrogen by improving the soil physicochemical properties (such as increasing SWC and reducing soil pH), and the effect is better under the restoration pattern of MG in the 20–40 cm soil layer and the restoration pattern of SG in the 40–60 cm soil layer. Therefore, in the process of the ecological restoration of Alpine sandy land under similar environments, adopting the ecological restoration patterns of MG and SG, while increasing the soil water content or reducing the soil pH, can effectively improve the supply and storage capacity of soil nitrogen, and then improve soil productivity.

4.4. Research Limitations and Prospects

This research shows that the time of the ecological restoration pattern will significantly affect the content and proportion of soil nitrogen components in the ecosystem [56], but this paper only studies the current restoration situation, and does not carry out the research on the time scale. Therefore, future research should explore the response of the soil nitrogen components content and its proportion to the restoration time in the process of ecological restoration.

Furthermore, in this study, it was found that the distribution of soil organic nitrogen components showed significant differences among the different soil layers in the process of

ecological restoration. The restoration pattern of MG significantly increased the content of soil nitrogen in the 20–40 cm soil layer, while the restoration pattern of SG significantly increased the content of soil nitrogen in the 40–60 cm soil layer, which may be related to plant roots. Therefore, future research should further carry out research on soil nitrogen components and root exudates in rhizosphere soil and non-rhizosphere soil under the ecological restoration pattern of Alpine sandy land in Northwest Sichuan, China, in order to further reveal the impact of plant roots on the ecological restoration of Alpine sandy land.

5. Conclusions

This study, through an analysis of the impact of various ecological restoration patterns on the soil nitrogen components, has revealed the overall and specific characteristics of soil nitrogen components. First, ecological restoration could significantly increase the contents of acid-lyzed total nitrogen, acylated ammonium nitrogen, acid-lyzed amino acid nitrogen, acid-lyzed unknown nitrogen and non-acid-lyzed nitrogen in soil, and the change trend was consistent with that of soil total nitrogen. Additionally, ecological restoration can increase the proportion of acid-lyzed amino acid nitrogen, acid-lyzed unknown nitrogen and non-acid-lyzed nitrogen to soil total nitrogen, and improve the transformation and storage capacity of soil nitrogen. The effect is most obvious in the 20–40 cm soil layer of the restoration pattern of mixed forage and the 40–60 cm soil layer of the restoration pattern of shrub combination. Generally, except acid-lyzed amino sugar nitrogen, the contents of the soil nitrogen components were positively correlated with the soil total nitrogen, soil water content and soil organic carbon, and negatively correlated with the soil bulk density and soil pH. In general, the three ecological restoration patterns can improve the soil nitrogen content by improving the soil water content, organic carbon content and reducing pH value, and the restoration pattern of the shrub combination is more conducive to the improvement of the soil nitrogen content, availability and supply capacity in the alpine sandy land in Northwest Sichuan, China. It can be seen that some vegetation in Alpine sandy land have complementary effects on the soil nutrient cycle. It is suggested to select the appropriate plant mixed seeding in the artificial ecological restoration pattern of sandy land and to create a variety of different configurations of mixed grassland in order to carry out the ecological restoration work in a more targeted manner.

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