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Research Article

Study on the Influence of Canopy Density on Cycling of Soil Available N in Different Landform of Loess Plateau in China

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Abstract

In this paper, a total of 330 soil samples with 0-100cm soil depth of 66 planted square forest (10*10m) with different canopy density in the Loess Plateau were selected for the determination and analysis of soil N content in different soil layers, and the effects of different canopy density on soil N cycle under different topographic factors of planted forest were studied. The results showed as follows: (1) the migration mechanism of different N forms to the root surface was different, the migration of nitrate nitrogen to the root surface mainly depended on mass flow, there was enrichment phenomenon near the root, ammonium nitrogen mainly through diffusion, resulting in deficiency and loss in the near rhizosphere, and the leaching loss of nitrate nitrogen was affected by soil water and root growth. (2) The thickness, composition and decomposition rate of litter were different due to different canopy density, which affected the content of ammonium nitrogen and nitrate nitrogen in forest soil. (3) Although the change of different regions in this region was spatially different, keeping the stand cover in the middle and high range of 0.75-0.8 can be conducive to maintaining the balance between the consumption of soil nutrients by the stand and the supplement of nutrient consumption, which can also be conducive to the sustainable recovery and growth of the stand in this region.

Keywords

Influence, Canopy Density, Cycling, Soil Available N, Landform, Loess Plateau

1. Introduction

Affected by climate, soil and biological transition, the typical zonal forest, grassland and desert vegetation in the northwest Loess Plateau are distributed in various habitats in scattered, scattered and plate form, which reflects the natural selectivity of tree (grass) species in this region under specific climatic conditions [1-4]. The long-term continuous artificial vegetation construction and ecological restoration and protection policies have restored the vegetation of the Loess Plateau to a certain extent, but there is still a cyclical decline phenomenon. *Hippophae rhamnoides Linn.* and *Caragana korshinskii* are the artificial populations of sustainable development and succession generally recognized at present. In the hilly and gully areas of the Loess Plateau where the precipitation is less than 550 mm, the branches of the two plantations die and the stands fail to self-renewal due to the dry soil layer [5]. For example, in the loess hilly area of the Hulu River basin located in the west of Liupan Mountain, the artificial *Robinia pseudoacacia L.* trees and *Populus simonii Carr* trees distributed on the top of mountain are distributed. Whether pure forest or mixed forest, most of them are me-

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dium and young forests with an age of 25 to 30 years. So far, although the stand structure is basically stable, there is also a widespread phenomenon of partial decline. Due to high-density planting and low natural rainfall (Especially in the northwest semi-arid area of the Hulu River basin), the phenomenon of branch aging and wilt occurs, and the dry layer of soil under the forest is very significant. The results showed that the shrub vegetation of *Hippophae rhamnoides Linn.* which originally grew under the forest died in a large area, and some plants withered and died. The above fully indicates that water is one of the most limiting factors for vegetation restoration in Northwest Loess Plateau [6-15].

In addition to soil moisture, soil nutrients are also important components of vegetation soil environment. Soil is the basis for the dynamic circulation and flow of carbon, nitrogen, phosphorus, potassium and other nutrient elements in the terrestrial ecosystem, and is the matrix for the normal growth and development of forests [16-20]. At the same time, forests play an important role in improving soil texture, enhancing species resources, enhancing water conservation functions, and promoting ecological restoration [21-25]. Therefore, soil and forest are interdependent communities. In the soil nutrient composition, nitrogen is the main component of nucleic acid and protein, and is an essential element for the formation of living organisms. As we all know, 78% of the composition of the atmosphere is N_2, but all plants, animals and most microorganisms can not directly use that but only ionic nitrogen (NH_4^+, NO^{3-}, etc.), and their amount in nature is far from meeting the needs of terrestrial vegetation growth. Only N_2 in molecular state can be transformed and recycled to meet the need of nitrogen nutrition in plants. Therefore, the inter-conversion of nitrogen substances is very important for vegetation growth.

Nitrogen in soil can be divided into inorganic nitrogen and organic nitrogen, among which the inorganic nitrogen that can be directly absorbed and utilized by plants mainly includes ammonium nitrogen and nitrate nitrogen. Vegetation obtains soil nitrogen by absorbing ammonium salt and nitrate from soil. The ammonium nitrogen absorbed into plants can directly combine with organic acids of photosynthesis products to form amino acids, and then form other nitrogen-containing organic matter. However, nitrate nitrogen can be absorbed and utilized only after it is reduced to ammonium nitrogen in plants. In the process of vegetation growth, the actual available nutrients only account for a small part of the total absorption of roots, so the migration of soil nutrients is an important factor affecting the availability of soil nutrients [26-30].

Canopy density affect not only the growth of plantation itself already but also of considerable impact on surface runoff and soil erosion. in the soil and water loss control, it can be usually determined by test to reduce soil loss to the minimum degree and can effectively reduce surface runoff and sediment erosion At the same time, because different canopy has a direct impact on the surface water heat condition, especially the light, it has an impact on the N nutrient cycle in the soil nutrients of the forest land, which is manifested by different ammoniation, nitrification and denitrification [31-38].

2. General Situation of Research Area

Pingliang is located in the center of the Loess Plateau and in the central and eastern part of Gansu Province in western China. It is divided into the Jinghe River Basin, a tributary of the Weihe River system in the Yellow River Basin in the east and the Hulu River basin in the west, with a total land area of 11119.07km^2. The climate type is temperate semi-humid and semi-arid climate, the average annual precipitation is 533.1mm, the average annual drought index is 1.65, the vegetation type is temperate forest grassland, the main species are deciduous broad-leaved forest, mixed forest, forest grassland, etc. The existing forest area is 354,702.23 hm^2, among of which 305,166.14 hm^2 is arbor forest, 49,536.09 hm^2 is shrub forest. There are 29 main tree species such as *Robinia pseudoacacia L.*, broad-leaved mixed forest, oak (*Quercus L.*), poplar (*PopulusL.*), *Larix gmelinii (Rupr.) Kuzen.*), Chinese pine (*P. tabuliformis* and other species in this region. The economic forest is mainly artificially planted red Fuji apple (*Malus pumila Mill*). There are 68572.19hm^2 of grassland, among which are mostly artificial grassland, there are more than 70 species, among which are mostly gramineae, compositae plants. The forest coverage rate has reached 33.8% that was higher than the average of 21.83% of that on the Loess Plateau. The coverage rate of forest and grass reached 50.57%, which was close to the average vegetation coverage rate of 59.0% on the whole Loess Plateau.

3. Research Methods

3.1. Woodland Quadrat Layout

In June 2022, the research team selected a total of 66 typical plantation standard samples in Pingliang City, Gansu Province, China, and investigated the stand structures (stand density, plant height, mean DBH (diameter at breast height), canopy density, biomass, etc.) and collected soil samples (for the determination and analysis of soil physical and chemical properties) of the planted forests in the region. The area of each sample was 100m^2 (10m×10m), covering different terrain (slope, slope direction and slope position) as much as possible. The slope, slope direction and altitude information of different slope site samples were measured by compass, slope meter and portable GPS locator. See Table 1.

Table 1. *Distribution of soil sampling points at different slope gradients, slope directions and slope positions.*

Slope direction	Slope position	Slope gradient	Number of sampling points	Slope direction	Slope position	Slope gradient	Number of sampling points
Shady slope	On the top	0~5°	4	Shady slope	On the top	0~5°	2
		5~15°	2			5~15°	2
		15~20°	0			15~20°	0
		20~25°	2			20~25°	0
		25~30°	0			25~30°	0
		>30°	0			>30°	0
	Up slope	0~5°	0		Up slope	0~5°	0
		5~15°	1			5~15°	0
		15~20°	2			15~20°	0
		20~25°	4			20~25°	0
		25~30°	0			25~30°	1
		>30°	3			>30°	1
	Middle slope	0~5°	0		Middle slope	0~5°	0
		5~15°	0			5~15°	0
		15~20°	3			15~20°	0
		20~25°	6			20~25°	0
		25~30°	0			25~30°	0
		>30°	0			>30°	0
	Down slope	0~5°	0		Down slope	0~5°	0
		5~15°	0			5~15°	0
		15~20°	0			15~20°	0
		20~25°	0			20~25°	1
		25~30°	0			25~30°	0
		>30°	0			>30°	0
Shady slope	On the top	0~5°	1	Shady slope	On the top	0~5°	1
		5~15°	1			5~15°	1
		15~20°	1			15~20°	0
		20~25°	0			20~25°	0
		25~30°	0			25~30°	1
		>30°	0			>30°	0
	Up slope	0~5°	0		Up slope	0~5°	0
		5~15°	0			5~15°	1
		15~20°	0			15~20°	2
		20~25°	0			20~25°	1
		25~30°	0			25~30°	2
		>30°	0			>30°	3
	Middle slope	0~5°	0		Middle slope	0~5°	0

Slope direction	Slope position	Slope gradient	Number of sampling points	Slope direction	Slope position	Slope gradient	Number of sampling points
		5~15°	0			5~15°	0
		15~20°	0			15~20°	0
		20~25°	1			20~25°	3
		25~30°	0			25~30°	3
		>30°	0			>30°	1
		0~5°	0			0~5°	1
		5~15°	0			5~15°	0
		15~20°	0			15~20°	1
	Down slope	20~25°	0		Down slope	20~25°	1
		25~30°	0			25~30°	3
		>30°	0			>30°	1

3.2. Sample Number Statistics of Forest Canopy Density Survey

Canopy density data were extracted from the survey data of stand structure (stand density, plant height, mean DBH, canopy density, canopy width, biomass, etc.), and the statistical results showed that the canopy density of the survey quadrat plantation ranged from 0.45 to 0.85, among which 42 quadrats had canopy density below 0.8 and 24 quadrats had canopy density above 0.8, as shown in Table 2.

Table 2. *Statistics of sample numbers.*

section	<0.8			≥0.8		total
Canopy density	**<0.7**	**0.7-0.75**	**0.75-0.8**	**0.8-0.85**	**≥0.85**	
Sample size	9	22	11	13	11	66
subtotal	42			24		66

3.3. Forest Soil Sampling and Determination Methods

3.3.1. Soil Sampling

According to the 5-point sampling method, soil samples were drilled into 5 different soil depths of 0 ~ 20, 20 ~ 40, 40 ~ 60, 60 ~ 80, 80 ~ 100cm in each plot, and the 5 soil layers were evenly mixed into one soil sample. A total of 330 soil samples were collected from 66 plantation plots. After the soil samples were dried naturally for a month, stones, roots and other debris were removed, and the appropriate amount of soil samples were taken by quarter method and screened by 0.25mm for the determination of soil chemical properties.

3.3.2. Determination of N in Soil

Soil N determination: soil nitrate nitrogen (NO^{3-}-N) content was determined by phenol disulfonic acid colorimetric method; Soil ammonium nitrogen (NH^{4+}-N) was determined by KCl extraction and indophenol blue colorimetry.

3.4. Results of Averaging the Measured Values

3.4.1. Soil Ammonium Nitrogen

The average content of ammonium nitrogen in woodland soil with different canopy density is shown in Table 3.

Table 3. Soil ammonium nitrogen content (mg/kg) in forestland with different canopy density.

subzone	Soil depth (cm)	Canopy density				
		<0.7	0.7-0.75	0.75-0.8	0.8-0.85	≥0.85
The whole area	0-20	25.14	37.21	30.42	27.92	23.50
	20-40	23.86	37.18	30.76	27.28	19.04
	40-60	23.20	35.10	29.95	22.96	20.62
	60-80	20.79	32.23	28.01	25.26	21.70
	80-100	19.84	29.81	30.94	26.18	23.56
	The average	22.57	34.31	30.01	25.92	21.68
wasteland and gully areas	0-20	——	65.24	12.91	——	——
	20-40	——	54.99	13.71	——	——
	40-60	——	58.29	14.80	——	——
	60-80	——	58.65	11.66	——	——
	80-100	——	46.45	11.79	——	——
	The average	——	56.72	12.97	——	——
Plateau and gully region	0-20	28.11	36.33	44.55	14.87	20.80
	20-40	18.46	19.34	20.21	17.18	16.96
	40-60	15.79	16.48	17.16	15.88	17.03
	60-80	17.02	16.79	16.55	12.61	18.15
	80-100	16.99	16.07	15.15	14.89	17.16
	The average	19.28	21.00	22.72	15.09	18.02
Hilly and gully areas	0-20	23.65	31.19	29.88	30.10	26.74
	20-40	26.56	33.00	32.67	28.96	21.54
	40-60	26.91	30.84	32.10	24.14	24.92
	60-80	22.67	26.06	29.97	27.37	25.94
	80-100	21.26	26.27	33.47	28.06	31.25
	The average	24.21	29.47	31.62	27.73	26.08

3.4.2. Soil Nitrate Nitrogen

The average soil nitrate nitrogen content of forest land with different canopy density is shown in Table 4.

Table 4. Soil nitrate nitrogen content (mg/kg) in forestland with different canopy density.

subzone	Soil depth (cm)	Canopy density				
		<0.7	0.7-0.75	0.75-0.8	0.8-0.85	≥0.85
The whole area	0-20	1.77	1.91	2.46	2.10	1.97
	20-40	1.53	1.44	2.29	1.78	1.50
	40-60	0.44	1.56	1.72	1.77	1.28
	60-80	0.60	1.08	1.10	1.12	1.06

subzone	Soil depth (cm)	Canopy density				
		<0.7	0.7-0.75	0.75-0.8	0.8-0.85	≥0.85
	80-100	0.51	0.52	0.78	0.66	0.88
	The average	0.97	1.30	1.67	1.49	1.34
wasteland and gully areas	0-20	——	1.59	0.75	——	——
	20-40	——	1.24	0.69	——	——
	40-60	——	1.55	0.01	——	——
	60-80	——	0.90	0.02	——	——
	80-100	——	0.63	0.73	——	——
	The average	——	1.18	0.44	——	——
Plateau and gully region	0-20	3.85	4.49	5.13	1.18	2.67
	20-40	2.21	2.56	2.91	2.92	1.88
	40-60	0.58	1.06	1.54	2.49	1.66
	60-80	1.01	0.96	0.91	1.28	1.43
	80-100	0.64	0.69	0.74	0.55	0.97
	The average	1.66	1.96	2.25	1.68	1.72
Hilly and gully areas	0-20	0.74	2.21	2.27	2.25	1.12
	20-40	1.18	1.34	2.31	1.60	1.04
	40-60	0.37	1.27	1.83	1.65	0.82
	60-80	0.39	1.24	1.17	1.10	0.61
	80-100	0.44	0.55	0.79	0.68	0.78
	The average	0.62	1.32	1.67	1.46	0.87

4. Result Analysis

4.1. Soil Ammonium Nitrogen Profile Analysis

Through the analysis of soil ammonium nitrogen profile of forest soil with different canopy density in different regions, the results showed that:

(1) The influence of canopy closure on the soil ammonium nitrogen content of forest land in the whole range is mainly reflected in the stand with medium and high canopy closure. In the forest with canopy closure > 0.7, the average soil ammonium nitrogen content in the 0-100cm soil layer shows a linear decreasing trend with the increase of canopy closure (see Figure 1). Therefore, the consumption of soil nutrients in the growth process of the lower canopy is less than that of the higher canopy. The variation of ammonium nitrogen content in soil samples ranged from 19.84mg/kg to 37.12mg/kg (see Table 3). From the analysis of the change of ammonium nitrogen content in the soil vertical profile, the difference of ammonium nitrogen content in the soil layer of the forest land with different canopy density was small, and there was no obvious surface aggregation effect, as shown in Figure 4(a).

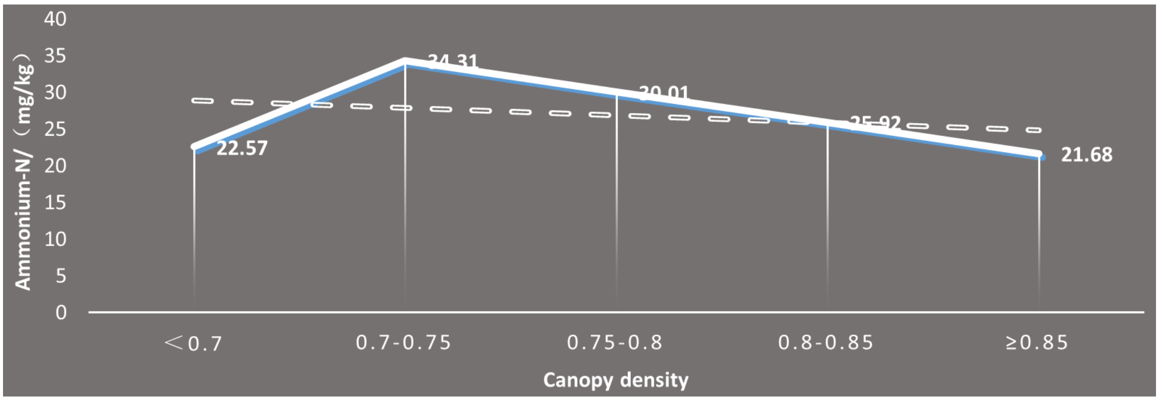


Figure 1. *Changes of the average content of ammonium nitrogen in the 0-100cm soil layer of forest land with different canopy density in the whole region.*

(2) Two kinds of forest land with the same canopy density of 0.7 ~ 0.75 and 0.75 ~ 0.8 in the gully area of the remnant tableland were compared and analyzed, and the results (see Table 3 and Figure 4(b)) showed that: The average content of ammonium nitrogen in 0-100cm soil layer of forest land with a canopy of 0.7-0.75 was significantly higher than that of forest land in other regions, reaching 56.72mg/kg, which was 1.65 times that of the whole region, 2.70 times that of the plateau region and 1.92 times that of the hilly region. However, the mean ammonium nitrogen content in the 0-100cm soil layer of forest land with a canopy degree of 0.75 to 0.8 was significantly lower than the mean of forest land samples in other regions, only 12.97mg/kg, which was lower than the mean of soil ammonium nitrogen in other regions under the same canopy degree. It is only 0.43 times that of the global sample, 0.57 times that of the plateau and gully region, and 0.41 times that of the hilly region. From the soil vertical profile analysis, canopy density had little effect on soil ammonium nitrogen between different layers in the 0-100cm soil layer, resulting in little difference in soil ammonium nitrogen content between different layers and no obvious surface polymerization effect, as shown in Figure 4(b).

(3) The effects of canopy density on soil ammonium nitrogen content in 0-100cm soil layer in the plateau gully region are as follows: For forest land with canopy closure < 0.75, soil ammonium nitrogen content increased linearly and slowly with the increase of canopy closure, but the increase amplitude was not large. For forest land with canopy closure > 0.8, soil ammonium nitrogen content generally decreased with the increase of canopy closure, and the average soil ammonium nitrogen content changed with the change curve of canopy closure (see Figure 2). Soil ammonium nitrogen content in 0-100cm soil layer of forest land ranged from 12.61mg/kg to 44.55mg/kg, as shown in Table 3.

(4) Canopy density in hilly and gully region has no significant effect on the soil ammonium nitrogen content, and the soil ammonium nitrogen content in 0-100cm soil layer of different canopy density has little difference (see Figure 3), indicating that the regulation of soil nutrient consumption and supply cycle in forest land is not affected by canopy density in this region. From the analysis of soil vertical profile, there was little difference in soil ammonium nitrogen content in different soil layers of woodland with different canopy density, as shown in Figure 4(d).

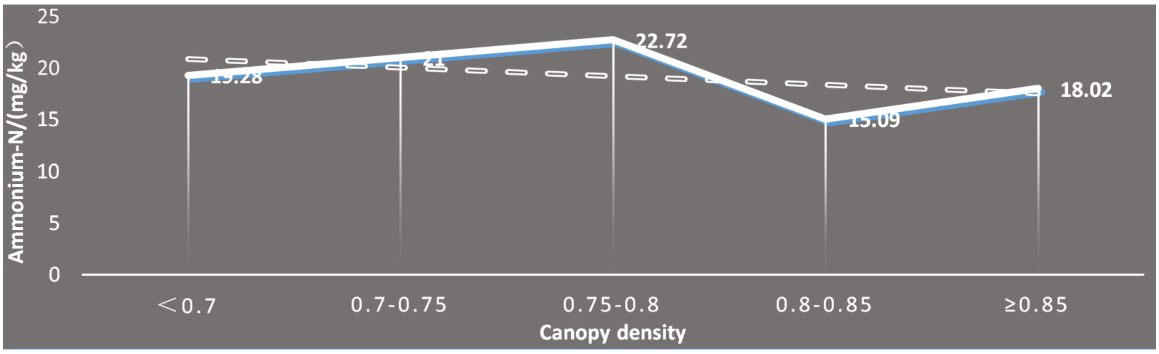


Figure 2. *Changes of the average content of ammonium nitrogen in 0-100cm soil layers of woodland with different canopy density in the plateau gully region.*

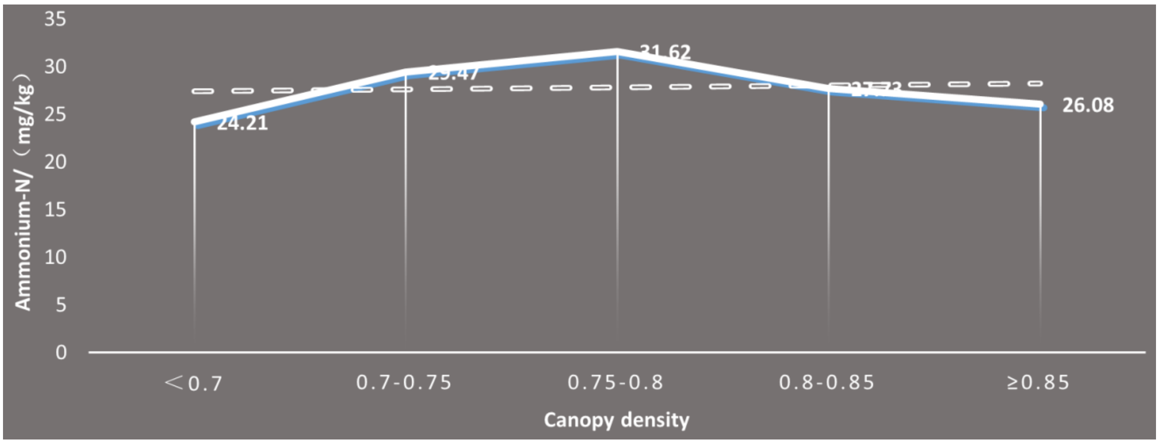
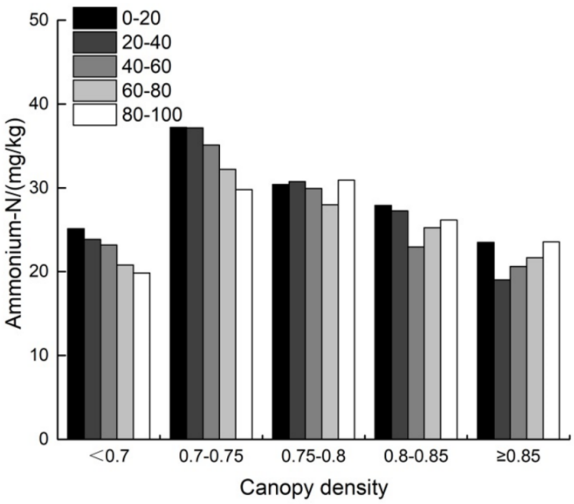
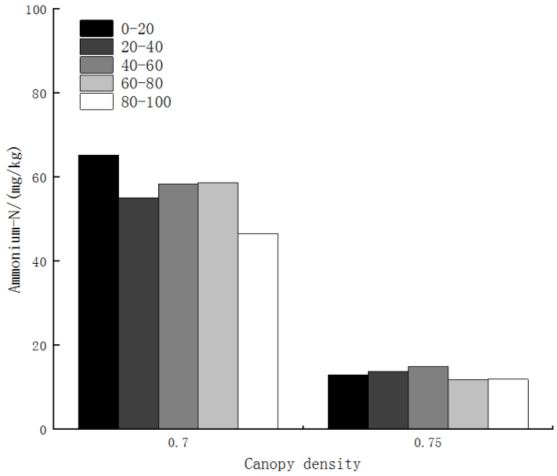


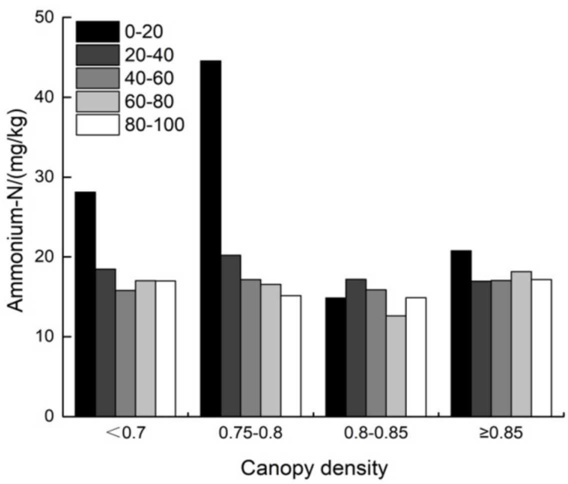
Figure 3. *Changes of the average content of ammonium nitrogen in 0-100cm soil layer of woodland with different canopy density in hilly and gully region.*



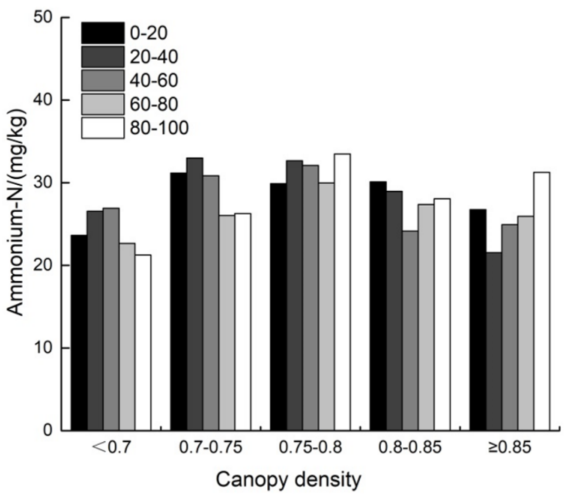
a. The whole area



b. wasteland and gully area



c. Plateau and gully region



d. Hilly and gully areas

Figure 4. *Soil ammonium nitrogen profiles in different regions with different canopy densities.*

4.2. Soil Nitrate N Profile Analysis

Through the analysis of soil nitrate nitrogen profile of forest land with different canopy density, the results showed that:

(1) The effects of canopy density on nitrate nitrogen content of forest soil in the whole range are as follows: For forest land with canopy density < 0.75, the average soil nitrate nitrogen content in 0-100cm soil layer increased linearly with the increase of canopy density, while for forest land with canopy density > 0.75, the average soil nitrate nitrogen content in 0-100cm soil layer decreased linearly with the increase of canopy density (see Figure 5). The results showed that the soil nutrient consumption was affected by the size of canopy density. Therefore, the soil nutrient consumption of lower canopy density was less than that of higher canopy density. The variation range of nitrate nitrogen content in the global sample was 0.44mg/kg ~ 2.46mg/kg (see Table 4). From the analysis of nitrate nitrogen content changes in the soil vertical profile, the content of nitrate nitrogen in the soil surface, shallow surface and upper layer of forest land with different canopy density was significantly different, and the surface polymerization effect of nitrate nitrogen was very obvious, as shown in Figure 8(a).

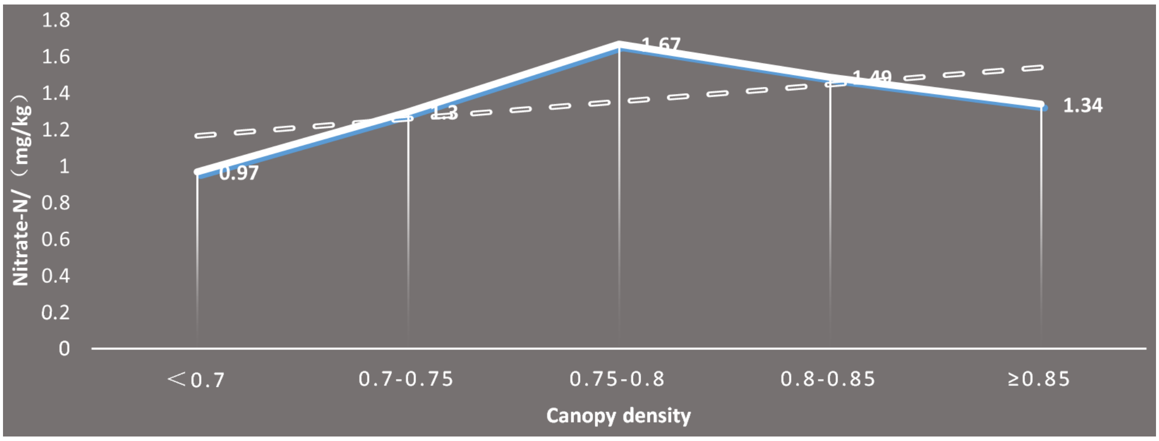


Figure 5. *Changes of average nitrate nitrogen content in 0-100cm soil layer of forest land with different canopy density in the whole region.*

(2) Two kinds of forest land with the same canopy density of 0.7 ~ 0.75 and 0.75 ~ 0.8 in the gully area of the remnant tableland were compared and analyzed, and the results showed that (see Table 4 and Figure 8(b)): The average soil nitrate nitrogen content in the 0-100cm soil layer of forest land with a canopy of 0.75 to 0.8 was significantly lower than that in other regions, only 0.44mg/kg, which was 0.26 times of the average in the whole region, 0.20 times of the average in the plateau and gully region, and 0.26 times of the average in the hilly region. However, the mean soil nitrate nitrogen content in the 0-100cm soil layer of forest land with a canopy degree of 0.7 to 0.75 had little difference with the mean of forest land samples in other regions, reaching 1.18mg/kg, but it was still lower than the mean of soil nitrate nitrogen in other regions. From the analysis of soil vertical profile, canopy degree has little influence on soil nitrate nitrogen content between different layers in the 0-100cm soil layer, so that the difference of soil nitrate nitrogen content between different layers is small, and the surface polymerization effect is not obvious, as shown in Figure 8(b).

(3) The effect of canopy closure on soil nitrate nitrogen content in 0-100cm soil layer in the plateau gully region was as follows: for forest land with canopy closure < 0.75, soil nitrate nitrogen content showed a linear and slow increase with the increase of canopy closure, and the mean value increased from 1.66mg/kg to 2.25mg/kg, an increase of 35.54%. Soil nitrate nitrogen content of forest land with canopy closure > 0.8 showed a decreasing change as a whole with the increase of canopy closure, and the mean value decreased from 2.25mg/kg to 1.72mg/kg, decreasing by 23.56%. The change range was small, indicating that the effect of stand canopy closure on soil nitrate nitrogen in this region was not obvious, and the change curve of average soil nitrate nitrogen content with canopy closure was shown in Figure 6. Soil nitrate nitrogen content in 0-100cm soil layer of forest land ranged from 0.55mg/kg to 5.13mg/kg, as shown in Table 4. From the analysis of soil vertical profile, the soil nitrate nitrogen content of forest land in this region has obvious surface accumulation characteristics. With the increase of soil depth, the soil nitrate nitrogen content of forest land with different canopy density basically shows a decreasing trend, but the changes are different, among which: The soil nitrate nitrogen content in the 0-100cm soil layer of forest land with a canopy degree < 0.8 had significant differences, while the soil nitrate nitrogen content in the 0-100cm soil layer of forest land with a canopy degree ≥0.85 had little differences, as shown in Figure 8(c).

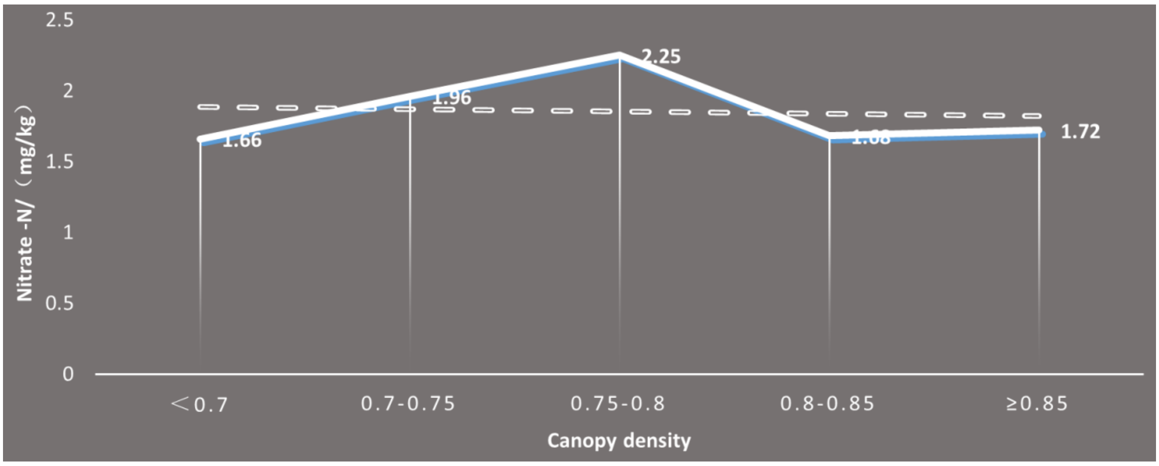


Figure 6. *Changes of average nitrate nitrogen content in 0-100cm soil layers of woodland with different canopy density in the gully region of the plateau.*

(4) The effect of canopy closure on soil nitrate nitrogen content in 0-100cm soil layer in hilly and gully region was as follows: for forest land with canopy closure < 0.75, soil nitrate nitrogen content increased with the increase of canopy closure, and the average value increased from 0.62mg/kg to 1.67mg/kg, increasing by 59.05%. Soil nitrate nitrogen content of forest land with canopy density > 0.8 decreased with the increase of canopy density, and the mean value decreased from 1.67mg/kg to 0.87mg/kg, decreasing by 47.9%. The change range was also large, indicating that stand canopy density in this region had a great influence on soil nitrate nitrogen, and the change curve of average soil nitrate nitrogen content with canopy density was shown in Figure 7. In the 0-100cm soil layer of forest land, the soil nitrate nitrogen content ranged from 0.37mg/kg to 2.31mg/kg, and the soil nitrate nitrogen content in 20-40cm soil of forest land with a canopy density < 0.7 was the highest (1.18mg/kg). The highest nitrate nitrogen content in 0-20cm and 20-40cm soil of forest land with a canopy density of 0.75 ~ 0.8 was 2.27mg/kg and 2.31mg/kg, respectively, as shown in Table 4. From the analysis of the soil vertical profile, the soil nitrate nitrogen of forest land in this region showed obvious surface accumulation characteristics. With the increase of soil depth, the soil nitrate nitrogen content of forest land with different canopy density basically showed a decreasing trend, as shown in Figure 8(d).

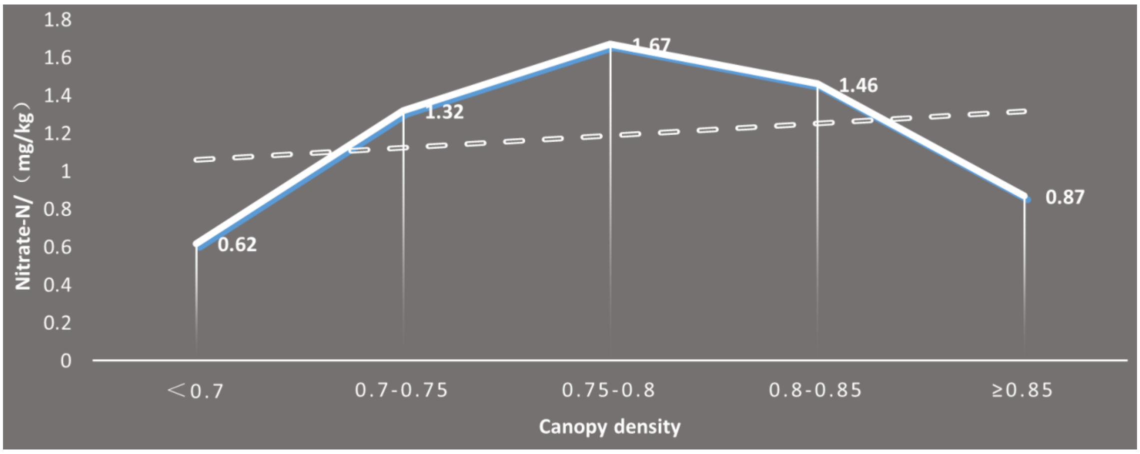
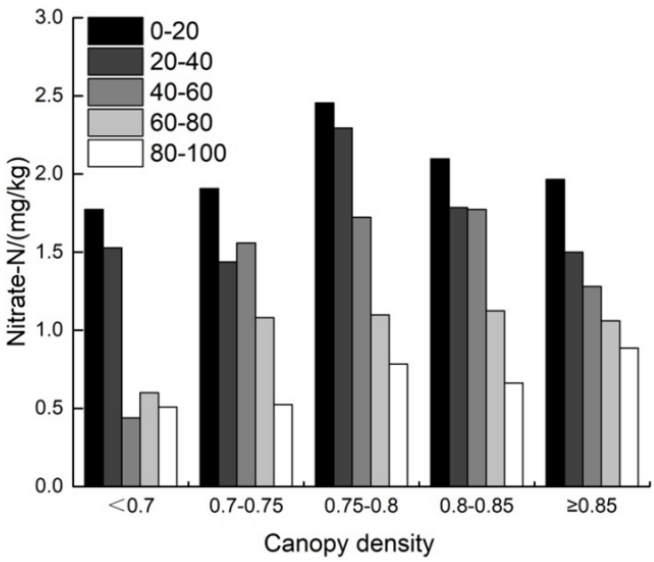
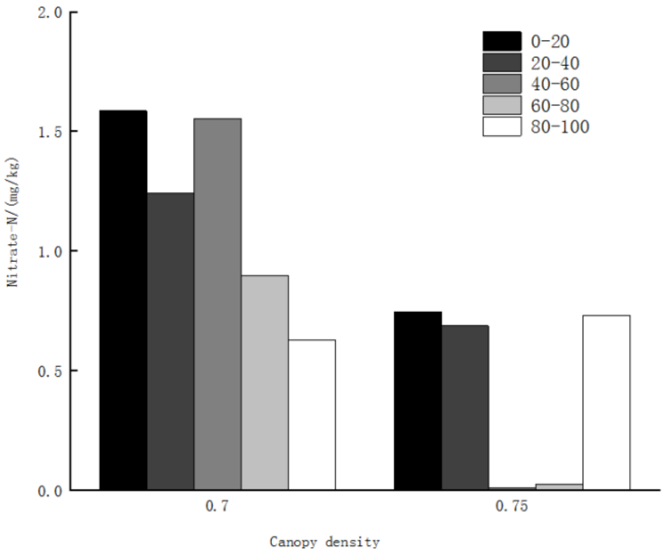


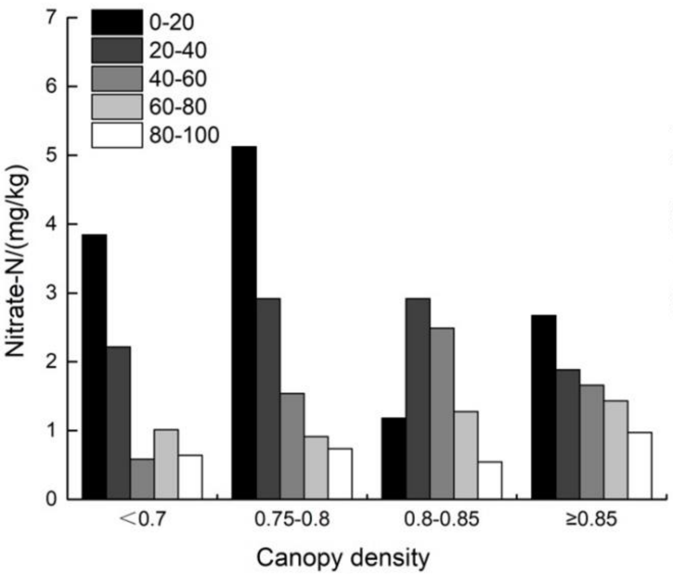
Figure 7. *Changes of average nitrate nitrogen content in 0-100cm soil layers of woodland with different canopy density in hilly and gully region.*



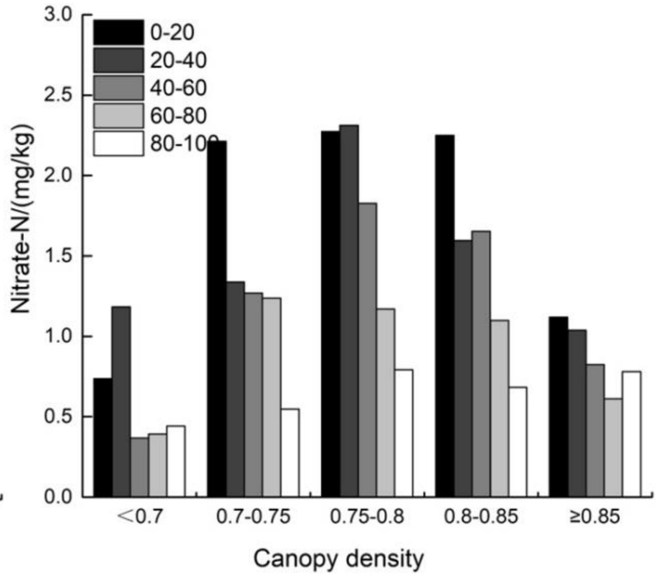
a. The whole area



b. wasteland and gully area



c. Plateau and gully region



d. Hilly and gully areas

Figure 8. *Soil nitrate nitrogen profiles of woodland with different canopy density in different regions.*

5. Correlation Analysis of Transport Cycles of Ammonium N and Nitrate N in Forest Soil

On the one hand, the changes in the concentrations of ammonium nitrogen and nitrate nitrogen in forest soil comprehensively reflect the root consumption of soil N in the process of vegetation growth, the mineralization and replenishment of organic matter generated by the decomposition of litter under the forest under the action of soil microorganisms (mineralization process of organic N), the retention of soil N by microorganisms, and the effects of nitrification and denitrification. On the other hand, it is related to leaching loss caused by different hydrothermal conditions and soil physical and chemical properties in vegetation growth environment, in which NO_3^- leaching loss is the main, but NH_4^+ leaching loss may also occur in sandy soil. The leaching of nitrogen was more in the soil in moist and subhumid areas. In arid and semi-arid areas, NO_3^- leaching is less. The loss of nitrate was related to vegetation. The denser the roots of vegetation, the stronger the N absorption, and the less the accumulation of nitrate in soil. However, in humid and subhumid areas, the nitrate in the soil is susceptible to leaching and loss through denitrification under the action of rainfall, so the amount of nitrogen leaching depends on soil, climate and other conditions. The leaching nitrate can enter the river or groundwater with surface runoff and increase the nitrogen load in the water body. The migration and change of soil inorganic N in the vertical profile of forest soil are mainly manifested as the accumulation to the surface layer and the absorption and consumption of deep roots near the rhizosphere. By analyzing the correlation of inorganic N in different soil layers in different regions, the migration of inorganic N in soil and the conversion relationship between ammonium nitrogen and nitrate nitrogen can be revealed.

Through the correlation analysis of the average content of ammonium nitrogen and nitrate nitrogen in the 0-100cm forest soil layer of different landform types in the same group and region, the results showed that:

5.1. Correlation Analysis of the Total Area

Among soil inorganic N elements, only the same inorganic N elements in different soil layers are correlated, among which:

(1) The concentration of ammonium nitrogen in soil at different soil depths showed a very significant positive correlation ($P<0.01$), but the significance was different. The correlation coefficients were sorted as follows: Ammonium nitrogen 60-80/80-100 > Ammonium nitrogen 20-40/40-60 > Ammonium nitrogen 40-60/60-80 > Ammonium nitrogen 0-20/60-40 > Ammonium nitrogen 0-20/60-80 > Ammonium nitrogen 20-40/60-80 > Ammonium nitrogen 4-060/80-100 > ammonium nitrogen 0-20/40-60 > Ammonium nitrogen 0-20/40-60 > Ammonium nitrogen The state nitrogen 0-20/80-100 was higher than the ammonium nitrogen 20-40/80-100, and the corresponding correlation coefficients were 0.863, 0.835, 0.826, 0.781, 0.755, 0.745, 0.736, 0.703, 0.674, 0.610 (see Table 5). The results showed that the changes of ammonium nitrogen concentration were most similar in the deep adjacent soil layers of 60-80cm and 80-100cm, while the changes of ammonium nitrogen in the shallow surface of 20-40cm and the deep layer of 80-100cm were relatively different, and the correlation decreased. The reason for this phenomenon is that the surface accumulation of soil ammonium nitrogen in the vertical profile of the soil is not synchronized with the absorption and consumption of deep roots, which means that there is a big difference between the enrichment rate of soil ammonium nitrogen in the shallow surface and the absorption and consumption rate of deep roots.

(2) Soil nitrate nitrogen concentrations at different soil depths showed extremely significant and significant positive correlations at 0.01 and 0.05 levels, respectively, and were ranked as follows by correlation coefficient ($P<0.01$): Nitrous nitrogen 40-60/60-80 > nitrous nitrogen 60-80/80-100 > nitrous nitrogen 20-40/40-60 > nitrous nitrogen 0-20/20-40 > nitrous nitrogen 20-40/60-80 > nitrous nitrogen 40-60/80-100 > nitrous nitrogen 20-40/80-100, and the corresponding correlation coefficients are as follows: 0.781, 0.718, 0.687, 0.583, 0.526, 0.506, 0.488 (see Table 5); According to the correlation coefficient ($P<0.05$), the order is as follows: nitrate nitrogen 0-20/40-60 > nitrate nitrogen 0-20/60-80 > nitrate nitrogen 0-20/80-100, and the corresponding correlation coefficients are 0.307, 0.285, 0.257 (see Table 5). The results showed that the changes of soil nitrate nitrogen concentration were most similar in the adjacent depths of 40-60cm and 60-80cm, while the changes of soil nitrate nitrogen in the shallow surface 20-40cm and the deep depth 80-100cm were relatively different, and the correlation of concentration changes decreased.

Based on the above correlation analysis, it can be seen that the distribution characteristics of soil ammonium nitrogen and nitrate nitrogen in the shallow surface 20-40cm and deep layer 80-100cm of the root distribution are basically the same, that is, the N transport between the concentration enrichment changes in the surface layer and the consumption in the near rhizosphere of the deep root is not obvious. On the other hand, in the deeper soil layer, the soil N concentration changed significantly between soil layers, which was conducive to the absorption of soil N by stand roots and the promotion of growth.

Table 5. *Correlation coefficients of ammonium nitrogen and nitrate nitrogen in different soil layers of the total area.*

Soil layer /(cm)	Ammonium-N0-20	Ammonium-N20-40	Ammonium-N40-60	Ammonium-N60-80	Ammonium-N80-100	Nitrate-N0-20	Nitrate-N20-40	Nitrate-N40-60	Nitrate-N60-80	Nitrate-N80-100
Ammonium-N0-20	1									
Ammonium-N20-40	0.781**	1								
Ammonium-N40-60	0.703**	0.835**	1							
Ammonium-N60-80	0.755**	0.745**	0.826**	1						

Soil layer /(cm)	Ammo-ni-um-N0-20	Ammo-ni-um-N20-40	Ammo-ni-um-N40-60	Ammo-ni-um-N60-80	Ammo-ni-um-N80-100	Ni-trate-N0-20	Ni-trate-N20-40	Ni-trate-N40-60	Ni-trate-N60-80	Ni-trate-N80-100
Ammonium-N80-100	0.674**	0.610**	0.736**	0.863**	1					
Nitrate-N0-20	0.089	-0.048	0.077	0.125	0.069	1				
Nitrate-N20-40	-0.033	-0.127	-0.065	0.009	0.028	0.583**	1			
Nitrate-N40-60	-0.135	-0.152	-0.157	-0.156	-0.144	0.285*	0.687**	1		
Nitrate-N60-80	-0.120	-0.114	-0.121	-0.123	-0.047	0.257*	0.526**	0.781**	1	
Nitrate-N80-100	-0.096	-0.141	-0.080	-0.040	0.029	0.307*	0.488**	0.506**	0.718**	1

Note: * means significant correlation at 0.05 level; ** means very significant correlation at 0.01 level.

5.2. Correlation Analysis in the Gully Area of the Gully Tableland

(1) The concentration of ammonium nitrogen in 20-40cm and 60-80cm soil layers showed a significant positive correlation ($P<0.05$), and the correlation coefficient was 0.998 (see Table 6). The results showed that the changes of soil ammonium nitrogen concentration were most similar in the interlayer of 20-40cm and 60-80cm of forest land. This correlation change was conducive to the migration of soil ammonium nitrogen from superficial surface layer to deeper layer under leaching, so as to supplement the absorption of soil nutrients by deep root rhizosphere. The soil ammonium nitrogen concentration in the deep rhizosphere increased with the increase of the soil ammonium nitrogen concentration in the shallow surface soil, so that the rhizosphere nutrient cycle supply and supplement maintained a sustainable change. (2) The concentrations of ammonium nitrogen and nitrate nitrogen in 0-20cm surface soil of forest land showed a significant negative correlation ($P<0.05$), and the correlation coefficient was -0.999 (see Table 6). The results indicated that the change of ammonium nitrogen concentration in the surface soil could not improve the soil nitrate nitrogen content in the gully area of the northern Jinghe River Basin, which may be related to the soil texture in this area. According to the investigation, this area is covered by the fourth-grade loess with a thickness of 30-120m. The surface structure is Pleistocene Malan loess, the lithology is sub-sand and sub-clay, and the soil is mainly Hulu soil and yellow loessian soil. Most of the slopes on the tableland are Lishi loess, the lithology is clay, and the soil is mainly yellow spongy soil, mostly Wucheng loess on both sides of the gully slope and gully valley, and the soil is mostly yellow spongy soil and red colloidite, containing stone. Therefore, the woodland soil in this area has low porosity and poor soil aeration, which affects the microbial activity and prevents the conversion of soil ammonium nitrogen into nitrate nitrogen through nitrification, thus increasing the concentration of soil nitrate nitrogen. This change is not conducive to the effective conversion and transport of soil nutrients, thus limiting the growth of vegetation.

Table 6. *Correlation coefficients of ammonium nitrogen and nitrate nitrogen in soils of different soil layers in wasteland and gully region.*

Soil layer /(cm)	Ammo-ni-um-N0-20	Ammo-ni-um-N20-40	Ammo-ni-um-N40-60	Ammo-ni-um-N60-80	Ammo-ni-um-N80-100	Ni-trate-N0-20	Ni-trate-N20-40	Ni-trate-N40-60	Ni-trate-N60-80	Ni-trate-N80-100
Ammonium-N0-20	1									
Ammonium-N20-40	0.909	1								
Ammonium-N40-60	0.726	0.947	1							
Ammonium-N60-80	0.935	0.998*	0.923	1						
Ammonium-N80-100	0.826	0.986	0.987	0.972	1					
Nitrate-N0-20	-0.999*	-0.923	-0.750	-0.947	-0.846	1				

Soil layer /(cm)	Ammonium-N0-20	Ammonium-N20-40	Ammonium-N40-60	Ammonium-N60-80	Ammonium-N80-100	Nitrate-N0-20	Nitrate-N20-40	Nitrate-N40-60	Nitrate-N60-80	Nitrate-N80-100
Nitrate-N20-40	-0.131	0.295	0.587	0.229	0.451	0.095	1			
Nitrate-N40-60	-0.111	-0.515	-0.764	-0.455	-0.652	0.146	-0.971	1		
Nitrate-N60-80	0.599	0.211	-0.115	0.277	0.044	-0.570	-0.872	0.729	1	
Nitrate-N80-100	0.924	0.681	0.409	0.729	0.548	-0.910	-0.499	0.277	0.859	1

Note: * means significant correlation at 0.05 level; ** means very significant correlation at 0.01 level.

5.3. Correlation Analysis in the Plateau Gully Region

In this region, there are extremely significant or significant correlations between ammonium nitrogen in some soil layers and between ammonium nitrogen and nitrate nitrogen in some soil layers. In order of correlation coefficient ($P<0.01$), they are as follows: Ammonium nitrogen 40-60/80-100 > nitrate nitrogen 60-80/80-100 > nitrate nitrogen 40-60/60-80 > ammonium nitrogen 20-40/80-100 > ammonium nitrogen 60-80/80-100 > ammonium nitrogen 20-40/40-60, and the correlation coefficients are as follows: 0.897, 0.809, 0.775, 0.754, 0.770, 0.678; Nitrate nitrogen 20-40/40-60 > nitrate nitrogen 40-60/80-100 > ammonium nitrogen 40-60/60-80 > nitrate nitrogen 20-40/40-60 > ammonium nitrogen 20-40/60-80 > nitrate nitrogen 20-40/80-100, and the correlation coefficients ($P<0.05$) were as follows: 0.651, 0.633, 0.616, 0.606, 0.584, 0.584 (see Table 7). Therefore, there was a significant correlation between soil inorganic N in this region and adjacent soil layers, indicating that soil N circulation was better under certain hydrothermal conditions, which was conducive to stand growth.

Table 7. *Correlation coefficients of ammonium nitrogen and nitrate nitrogen in soils of different soil layers in the plateau gully region.*

Soil layer /(cm)	Ammonium-N0-20	Ammonium-N20-40	Ammonium-N40-60	Ammonium-N60-80	Ammonium-N80-100	Nitrate-N0-20	Nitrate-N20-40	Nitrate-N40-60	Nitrate-N60-80	Nitrate-N80-100
Ammonium-N0-20	1									
Ammonium-N20-40	0.396	1								
Ammonium-N40-60	0.388	0.678**	1							
Ammonium-N60-80	0.220	0.584*	0.616*	1						
Ammonium-N80-100	0.180	0.754**	0.897**	0.770**	1					
Nitrate-N0-20	-0.211	-0.266	-0.181	0.197	-0.151	1				
Nitrate-N20-40	0.066	0.365	0.076	0.301	0.103	0.507	1			
Nitrate-N40-60	0.192	0.606*	0.446	0.263	0.437	-0.047	0.651*	1		
Nitrate-N60-80	0.260	0.355	0.236	0.209	0.201	0.110	0.508	0.775**	1	
Nitrate-N80-100	0.285	0.260	0.326	0.210	0.181	0.273	0.584*	0.633*	0.809**	1

Note: * means significant correlation at 0.05 level; ** means very significant correlation at 0.01 level.

5.4. Correlation Analysis in the Loess Hilly and Gully Region

(1) The concentration of ammonium nitrogen in soil at different soil depths showed a very significant positive correlation (P<0.01), but the significance was different. The correlation coefficients were sorted as follows: Ammonium nitrogen 80-100 > ammonium nitrogen 20-40 > Ammonium nitrogen 40-60 > ammonium nitrogen 60-80 > ammonium nitrogen 20-80 > ammonium nitrogen 20-60 > ammonium nitrogen 20-100 > ammonium nitrogen 40-80 > ammonium nitrogen 60-100 > ammonium nitrogen 40-100, and the corresponding correlation coefficients are as follows: 0.863, 0.831, 0.819, 0.803, 0.790, 0.737, 0.726, 0.715, 0.699, 0.559 (see Table 8). The results showed that the changes of ammonium nitrogen concentration were most similar in the deep adjacent soil layers of 60-80cm and 80-100cm, while the changes of ammonium nitrogen in the shallow surface of 20-40cm and the deep layer of 80-100cm were relatively different, and the correlation decreased. The reason for this phenomenon is that the surface accumulation of soil ammonium nitrogen in the vertical profile of the soil is not synchronized with the absorption and consumption of deep roots, which means that there is a big difference between the enrichment rate of soil ammonium nitrogen in the shallow surface and the absorption and consumption rate of deep roots.

(2) The concentration of soil nitrate nitrogen in different soil depths also showed significant positive correlation, and the correlation coefficient (P<0.01) was sorted as follows: Nitrous nitrogen 60-80 > nitrous nitrogen 80-100 > nitrous nitrogen 40-60 > nitrous nitrogen 20-40 > nitrous nitrogen 40-80 > nitrous nitrogen 60-100 > nitrous nitrogen 40-100, and the corresponding correlation coefficients are as follows: 0.781, 0.718, 0.687, 0.583, 0.526, 0.506, 0.488 (see Table 8); The order by correlation coefficient (P<0.05) is as follows: Nitrous nitrogen 60-80 > nitrous nitrogen 40-60 > nitrous nitrogen 80-100 > nitrous nitrogen 20-40 > nitrous nitrogen 40-100 > nitrous nitrogen 40-100 > nitrous nitrogen 20-100 > nitrous nitrogen 20-100 > nitrous nitrogen 20-80, and the corresponding correlation coefficients are as follows: 0.790, 0.718, 0.694, 0.651, 0.534, 0.477, 0.465, 0.441, 0.368, 0.365 (see Table 8). The results showed that the changes of soil nitrate nitrogen concentration were most similar in the adjacent depths of 40-60cm and 60-80cm, while the changes of soil nitrate nitrogen in the shallow surface 20-40cm and the deep depth 60-100cm were relatively different, and the correlation of concentration changes decreased.

Table 8. *Correlation coefficients of ammonium nitrogen and nitrate nitrogen in different soil layers in loess hilly and gully region.*

Soil layer /(cm)	Ammonium-N0-20	Ammonium-N20-40	Ammonium-N40-60	Ammonium-N60-80	Ammonium-N80-100	Nitrate-N0-20	Nitrate-N20-40	Nitrate-N40-60	Nitrate-N60-80	Nitrate-N80-100
Ammonium-N0-20	1									
Ammonium-N20-40	0.831**	1								
Ammonium-N40-60	0.737**	0.819**	1							
Ammonium-N60-80	0.790**	0.715**	0.803**	1						
Ammonium-N80-100	0.726**	0.559**	0.699**	0.863**	1					
Nitrate-N0-20	-0.067	-0.035	0.052	0.094	0.096	1				
Nitrate-N20-40	-0.198	-0.193	-0.101	-0.111	-0.135	0.651**	1			
Nitrate-N40-60	-0.103	-0.112	-0.061	-0.095	-0.094	0.441**	0.718**	1		
Nitrate-N60-80	-0.070	-0.096	-0.082	-0.008	-0.011	0.365**	0.534**	0.790**	1	
Nitrate-N80-100	-0.086	-0.092	-0.1010	-.0071	-.0104	0.368**	0.465**	0.477**	0.694**	1

6. Conclusion

The analysis showed that: (1) the migration mechanism of different N forms to the root surface was different, the migration of nitrate nitrogen to the root surface mainly depended on mass flow, there was enrichment phenomenon near the root, ammonium nitrogen mainly through diffusion, resulting in deficiency and loss in the near rhizosphere, and the leaching loss of nitrate nitrogen was affected by soil water and root growth. (2) The thickness, composition and decomposition rate of litter were different due to different canopy density, which affected the content of ammonium nitrogen and nitrate nitrogen in forest soil. Generally, due to the better hydrothermal ventilation condition of the soil surface, the decomposition rate of the surface fine roots and litter was accelerated, which was conducive to the growth and reproduction of microorganisms and played a role in promoting the accumulation of soil nutrients. However, with the increase of the soil depth, the microbial activity decreased, and the content of ammonium nitrogen and nitrate nitrogen formed by decomposition and transformation also decreased. The absorption of deep roots consumed a certain amount of soil nutrients, which caused the vertical distribution of soil nutrients to surface aggregation. (3) According to the change of the mean content of ammonium nitrogen and nitrate nitrogen with the canopy density in the 0-100cm soil layer, too high or too low canopy density will lead to the loss of ammonium nitrogen and nitrate nitrogen content in soil nutrients, which was not conducive to the sustainable restoration and renewal of stand. Although the change of different regions in this region was spatially different, keeping the stand cover in the middle and high range of 0.75-0.8 was conducive to maintaining the balance between the consumption of soil nutrients by the stand and the supplement of nutrient consumption, which was conducive to the sustainable recovery and growth of the stand in this region.

Abbreviations

DBH: Diameter at Breast Height

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Ding Wenbin, Wang Fei. Effects of vegetation construction on soil moisture in Loess Plateau [J]. Acta Ecologica Sinica, 202, 42(13): 5531-5542. (in Chinese) https://doi.org/10.5846/stxb202107191941

[2] Zhao Zhong, Li Jian, Yuan Zhifa, et al. Mathematical model of vertical change of soil moisture in the forest land of Black Locust in loess [J]. Scientia Silvae Sinicae, 2009, 45(10): 9-13. https://doi.org/10.11707/j.1001-7488.20091002

[3] Li Xiaoying, Duan Zhenghu, Tan Mingliang, et al. Study on the relationship between vegetation distribution and soil moisture in the western hilly region of the Loess Plateau under different precipitation conditions [J]. Chinese Journal of Soil Science, 2014, 45(02): 364-369. https://doi.org/10.19336/j.cnki.trtb.2014.02.018

[4] HU L J. Soil water ecological environment of vegetation restoration in Loess Plateau [D]. Northwest A & F University, 2002: 1-2. (in Chinese)

[5] [ZHANG W H, LIU G B, vegetation restoration and construction strategies in Loess Plateau. Soil and Water Conservation in China, 2009, (1): 24-26.] https://doi.org/10.14123/j.cnki.swcc.2009.01.008

[6] Zhao Y L. Research on deep soil water at different scales in loess region [D]. University of Chinese Academy of Sciences (Research Center for Soil and Water Conservation and Ecological Environment of the Ministry of Education, Chinese Academy of Sciences), 2017: 1-2. (in Chinese)

[7] Zhang Jingjing, Wang Li. Study on surface soil moisture in loess Plateau and gully region [J]. Bulletin of Soil and Water Conservation, 2011, 31(1): 93-97. https://doi.org/10.13961/j.cnki.stbctb.2011.01.029

[8] Yang Yahui, Zhao Wenhui, et al. Effects of different vegetation on soil water distribution in gully region of Loess Plateau [J]. Research of Soil and Water Conservation [Research, 2018, 25(4): 60-64. https://doi.org/10.13869/j.cnki.rswc.20180111.001

[9] ZHANG L Y, Di L, Ren Y B, et al. Soil water difference analysis of different vegetation measures in Zhonggou small watershed of Longdong Loess Plateau [J]. Research of Soil and Water Conservation, 2021, 28(04): 159-164+170. (in Chinese) https://doi.org/10.13869/j.cnki.rswc.2021.04.021

[10] Hu Wei, Shao Mingan, WANG Quanjiu. Scale study on spatial variation of soil water in reclaimed slope of Loess Plateau [J]. Transactions of the Chinese Society of Agricultural Engineering, 2005(8): 11-16.

[11] Wu Guanyu. Water use efficiency and its influencing factors of typical farmland conversion to forest in loess hilly region [J]. Water Saving Irrigation, 2021(10): 78-83, 88.

[12] Ma Xianghua, Bai Wenjuan, Jiao Juying, et al. Study on soil water change during vegetation restoration in the Loess hilly and gully region [J]. Bulletin of Soil and Water Conservation, 2004(05): 19-23. https://doi.org/10.13961/j.cnki.stbctb.2004.05.005

[13] Zhang Yongwang, Wang Jun, Qu Yatan, et al. Evaluation of soil water availability during vegetation restoration in the Loess Plateau [J]. Journal of Irrigation and Drainage, 2019, 39(06): 79-85, 114.

[14] Li Xiaoying, Duan Zhenghu. Research progress on the interaction between soil water and vegetation in the Loess Plateau [J]. Chinese Journal of Soil Science, 2012, 43(06): 1508-1514. (in Chinese) https://doi.org/10.19336/j.cnki.trtb.2012.06.040

[15] WANG Fu, HE Q, ZHAO Q, Sha X Y, Zhang H, Han F, Soil moisture change of water conservation forest during vegetation restoration in loess hilly and gully region: A case study ofHulu River Basin in Pingliang City, China, 2023, (8): 26-30. https://doi.org/10.14123/j.cnki.swcc.2023.0180

[16] LIU Chaohua, Li Fengqiao, Liao Yangwenke, et al. Research progress on the influence process of plantation on soil fertility and its control [J]. Acta Pedologica Sinica, 2023, 60 (3): 644-656. (in Chinese) https://doi.org/10.11766/trxb202112020653

[17] YAN Xin, AN Hui, LIU Rentao. Effects of Desertification on Soil Physiochemical Properties of Desert Grassland. Soils, 2019, 51(5): 1006-1012. https://doi.org/10.13758/j.cnki.tr.2019.05.023

[18] Guo Q, Wen ZM, Zheng C, et al. Effects of Robinia pseudoacacia on the undergrowth of herbaceous plants and soil properties in the Loess Plateau of China. Journal of Plant Ecology, 2021, 14: 896-910.

[19] Christine Heuck, Alfons Weig, Marie Spohn. Soil microbial biomass C:N:P stoichiometry and microbial use of organic phosphorus. Soil Biology and Biochemistry, 2015, 85. https://doi.org/10.1016/j.soilbio.2015.02.029

[20] Fan Xinghuo, GE Hongyan, Zhang Shencan, et al. Soil fertility status of typical stand of ecological non-commercial forest in Jiangxi Province [J]. Journal of Beijing Forestry University, 2018, 40(11): 84-92. https://doi.org/10.13332/j.1000-1522.20180084

[21] Duan C W, Li X L, Chai Y, Xu W Y, Su L L, Ma P P, Yang X G. Effects of different rehabilitation measures on plant community and soil nutrient of degraded alpine meadow in the Yellow River Source. Acta Ecologica Sinica, 2022, 42(18): 7652-7662. https://doi.org/10.5846/stxb202104231063

[22] HU Xuehan, LIU Juan, JIANG Peikun, ZHOU Guomo, LI Yongfu, WU Jiasen. Effects of Change in Forest Type on Soil Organic Carbon in Soil Particles Relative to Size in Subtropical China [J]. Acta Pedologica Sinica, 2018, 55(6): 1485-1493. https://doi.org/10.11766/trxb201803140028

[23] HU Ercha, WANG Xiaojiang, WANG Zheng, et al. Characteristics of Understory Plant Community of Poplar Plantation in Mu Us Sandy Land [J]. Forest Research, 2023, 36(5): 189-197. https://doi.org/10.12403/j.1001-1498.20230134

[24] Bell F W, Lamb E G, Sharma M, Hunt S, Anand M, Dacosta J, Newmaster S G. Relative influence of climate, soils, and disturbance on plant species richness in northem temperate and boreal forests. Forest Ecology and Management, 2016, 381: 93-105. https://doi.org/10.1016/j.foreco.2016.07.016

[25] Zhang Ten. Soil quality evaluation of typical land use methods in hilly and gully areas of the Loess Plateau [D]. Yan 'an university, 2023. https://doi.org/10.27438/d.cnki.gyadu.2023.000343

[26] XI Li, LI Siyao, XIA Xiaoying, CHEN Yuwen, et al. Study on soil nutrient characteristics of Picea schrenkiana var. Tianschanica forest with different canopy densities [J]. Xinjiang Agricultural Sciences, 2023, 60(9): 2216-2222. https://doi.org/10.6048/j.issn.1001-4330.2023.09.016

[27] Li Binbin. The coupling mechanism and resilience of soil carbon, nitrogen and water during vegetation restoration in the China's Loess Plateau. University of Chinese Academy of Sciences (Research Center of Soil and Conservation and Ecological Environment, Chinese Academy of Sciences and Ministry of), 2021. https://doi.org/10.27558/d.cnki.gsthc.2021.000002

[28] YU Yunlong. Influence of gully control and land reclamation on nitrogen cycle and its internal mechanism in a small watershed of loess hilly region in northern Shaanxi Province [D]. University of Chinese Academy of Sciences (Institute of Earth Environment, Chinese Academy of Sciences), 2019.

[29] LI Changzhen. Soil Nitrogen Accumulation and Transformation Impact on Soil Carbon Pool Under Different Plantationsin the Loess Hilly Region of China [D]. Northwest A&F University, 2017.

[30] AI Zemin, CHEN Yunming, CAO Yang. Storage and allocation of carbon and nitrogen in Robinia pseudoacacia plantation at different ages in the loess hilly region, China. [J]. Chinese Journal of Applied Ecology, 2014, 25(02): 333-341. https://doi.org/10.13287/j.1001-9332.2014.0036

[31] Dong Yunzhong, Wang Yongliang, Zhang Jianjie, et al. Soil carbon and nitrogen storage of different land use types in northwestern Shanxi Loess Plateau [J]. Chinese Journal of Applied Ecology, 2014, 25(04): 955-960. https://doi.org/10.13287/j.1001-9332.2014.0069

[32] JIANG Yueli, ZHAO Tong, YAN Hao, et al. Effect of Different Land Uses on Soil Microbial Biomass Carbon, Nitrogen and Phosphorus in Three Vegetation Zones on Loess Hilly Area [J]. Bulletin of Soil and Water Conservation, 2013, 33(06): 62-68. https://doi.org/10.13961/j.cnki.stbctb.2013.06.027

[33] LI Ze, GUO Sheng-li, ZHANG Fang, ZOU Jun-liang. Effects of apple orchard converted from cropland on C and N storages in terrestrial system of slopping cultivated land in the Loess Gully Regions [J]. Journal of Plant Nutrition and Fertilizers, 2011, 17(4): 919-924. https://doi.org/10.11674/zwyf.2011.0510

[34] LIANG Ai-hua, HAN Xin-hui, ZHANG Yang, WANG Ping-ping, YANG Gai-he. Spatio-temporal Response of Soil Carbon and Nitrogen Relation to the Process of Vegetation Restoration in the Gully Region of Loess Plateau [J]. Acta Agrestia Sinica, 2013, 21(5): 842-849. https://doi.org/10.11733/j.issn.1007-0435.2013.05.002

[35] Deng L, Shangguan Z, Sweeney S. Correction: Changes in Soil Carbon and Nitrogen following Land Abandonment of Farmland on the Loess Plateau, China. [J]. PLoS ONE, 2013, 8(9): 101371 https://doi.org/10.1371/annotation/61b7e0d5-6062-49b7-a270-2c115dd3cb8f

[36] Gao Y, He N, Yu G, et al. Long-term effects of different land use types on C, N, and P stoichiometry and storage in subtropical ecosystems: A case study in China [J]. Ecological Engineering, 2014, 67171-181. https://doi.org/10.1016/j.ecoleng.2014.03.013

[37] Inselsbacher E. Recovery of individual soil nitrogen forms after sieving and extraction [J]. Soil Biology and Biochemistry, 2014, 71, 76-86. https://doi.org/10.1016/j.soilbio.2014.01.009

[38] Zhang He, Wang Fu, Zhao Qiang, Sha Xiao Yan, Wang Chun Ping,. Soil nutrient distribution characteristics and topographic factors of plantation: A case study of Pingliang City in eastern Gansu Province, China [J], Soil and water conservation in China, 2023(12): 44-48.