ISSN 2616-5872 Vol.6, Issue 1: 96-108, DOI: 10.25236/AJEE.2024.060114

The Influence of Different Vegetation Types on Soil C, N, P Content, and Their Stoichiometry in the Eastern Qilian Mountains' Binggou River Basin

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Abstract: *To investigate the impact of vegetation types on the ecological stoichiometry of soil carbon, nitrogen, and phosphorus, and to reveal the nutrient limitation and cycling patterns in the terrestrial ecosystem of a tributary, Quanshui River, in the upper reaches of the Shiyang River. The study focused on the marshland of Quanshui River, shrubland of Iris lacteal Pall and Potentilla fruticosa, and the forest of Picea crassifolia. The analysis covered the characteristics of soil organic carbon (SOC), total nitrogen (TN), total phosphorus (TP) content, and stoichiometric ratios in the 0-60cm soil depth across different vegetation types. The results indicated that: (1) In the 0-60cm soil layer, SOC was highest in shrubland, followed by forest and grassland. TN was highest in grassland, followed by forest and shrubland. In the 0-30cm soil layer, grassland exhibited significantly higher TP content compared to forest and shrubland. SOC, TN, and TP content in forest, grassland, and shrubland were higher in the 0-10cm layer compared to the 10-20cm layer. (2) Soil C:N, C:P, and N:P ratios were significantly influenced by different vegetation types. The C:N and C:P ratios were highest in shrubland, followed by forest and grassland. The N:P ratio was highest in grassland, followed by forest and shrubland. The vegetation growth in Quanshui River was found to be more limited by soil nitrogen than phosphorus. Therefore, based on the actual conditions of vegetation types, the rational application of nitrogen and phosphorus fertilizers is recommended to enhance nutrient retention in the soil and maintain ecological balance.*

Keywords: *Soil carbon; nitrogen and phosphorus; Ecological stoichiometry; Climate and vegetation types; Qilian mountains*

1. Introduction

Ecological stoichiometry is a discipline that explores the balance of energy and various chemical elements in ecosystems, as well as the relationships between organisms and the environment. It has been applied in various aspects, such as plant population dynamics, community succession, and ecosystem stability (Zeng et al., 2016; Zhang et al., 2019; Ma et al., 2021). It has also become an important tool for studying soil nutrient cycling. Soil is a crucial component of terrestrial ecosystems and the fundamental medium. Soil carbon, nitrogen, and phosphorus are the main constituents of soil nutrients, participating in processes such as plant growth and litter decomposition (Bai et al., 2012; Chen et al., 2016). Their concentrations can influence the dynamic changes of terrestrial ecosystems (Ma et al., 2021; Xu et al., 2020). The ratios of ecological stoichiometry are commonly used to detect nutrient limitations, describing important ecological processes and interactions between elements (Hättenschwiler and Jørgensen, 2010; Liu et al., 2020); they are effective tools for analyzing and explaining the changes and relationships between plants and the environment in ecosystems (Zeng et al., 2016). The ratios of C:N and C:P represent the ability of organisms to absorb carbon while simultaneously consuming nitrogen and phosphorus (Rong et al., 2015). In the net primary productivity of terrestrial ecosystems, the N:P ratio has been widely used as an indicator of nutrient limitations (Li et al., 2014). Therefore, exploring the temporal and spatial characteristics of carbon, nitrogen, and phosphorus stoichiometry helps us better understand nutrient patterns in terrestrial ecosystems and their

ISSN 2616-5872 Vol.6, Issue 1: 96-108, DOI: 10.25236/AJEE.2024.060114

potential impacts on ecosystem processes under environmental changes (Liu et al., 2021; Fang et al., 2019)[1-8].

The carbon, nitrogen, and phosphorus content, as well as their stoichiometric ratios in the soil, are influenced by various factors. For example, in arid and semi-arid regions where temperatures are high, rainfall is scarce, and evaporation is significant, the concentrations of soil carbon and nitrogen decrease. This arid condition inhibits vegetation growth, reducing the input of carbon and nitrogen into the soil. However, it is conducive to rock weathering, thereby increasing the concentration of phosphorus (Wang et al., 2022; Delgado-Baquerizo et al., 2013). Therefore, the content of soil carbon, nitrogen, and phosphorus is directly and indirectly influenced by surface vegetation types. Vegetation types can reflect differences in species composition and community structure, and they can also impact the physicochemical properties of the soil (Yan et al., 2013). Plant communities can improve soil fertility, resulting in significant differences in nutrient content among different vegetation types (Wang et al., 2012).

In recent years, extensive research has been conducted on the impact of different vegetation types on soil nutrients and their ecological stoichiometry. Due to the diverse geographical locations of vegetation, the results vary. In the eastern monsoon region, most studies indicate that soil nutrient content under forests is higher than that under grasslands, while there is no fixed conclusion regarding soil nutrient content under shrublands compared to forests and grasslands. For instance, in the karst region of Hechi City, Guangxi, the surface soil SOC and TP content of forests and shrublands are higher than that of grasslands, with TN content ranking as follows: forests > grasslands > shrublands (Su et al., 2019). Similarly, in Anshun City, also located in the karst region, the soil SOC and TN content of shrublands and forests are greater than that of grasslands (Guo et al., 2023). Xie et al. (2023) found that in the East Lake Wetland of Fuzhou, the surface soil SOC, TN, and TP content were higher in forests than in grasslands. In the loess hilly region, soil SOC, TN, and TP content in forests are higher than in grasslands (Liu et al., 2021; Zhu et al., 2013). In the Yanhe River Basin on the Loess Plateau, surface soil SOC and TN content in forests are higher than in grasslands (Zeng et al., 2016). In the asbestos river basin in the northeast region, forests have the highest soil SOC content, followed by grasslands, and shrublands have the lowest. Soil TN and TP content exhibit the following pattern: forests > shrublands > grasslands (Zang, 2023). In the Jilin Han National Nature Reserve, soil SOC and TN content in forests and shrublands are higher than in grasslands (Guan et al., 2023). In the arid and semi-arid northwest region, most research results indicate that soil nutrient content in forests and shrublands is higher than in grasslands. In the eastern edge of the Qilian Mountains, the 0-60cm soil layer SOC content ranks as follows: forests > shrublands > grasslands (Wang, 2014). In the Tianlaochi Basin of the Qilian Mountains, soil SOC and TN content follow the pattern: forests > shrublands > grasslands, while soil TP content exhibits the pattern: shrublands > forests > grasslands (Zhang et al., 2019). However, within the Qilian Mountains, different patterns exist. For example, on the central north slope of the Qilian Mountains, shrublands have the highest soil SOC content, followed by forests, with grasslands having the lowest. Surface soil TN content follows the pattern: shrublands > grasslands > forests, and mid-layer soil TN content follows the pattern: shrublands > forests > grasslands (Ai et al., 2010). Due to the unique geographical location of the Qilian Mountains and the intersection of three major natural zones, even within the same mountain range, research results differ. Therefore, it is essential to investigate the impact of different vegetation types on soil nutrients in different regions of the same natural zone[9-17].

The Qilian Mountains, located on the northeastern edge of the Qinghai-Xizang Plateau, serve as the headwaters for internal rivers such as the Shule River, Heihe River, and Shiyang River (Wang, 2014; Chen et al., 2016). They play a crucial role as an ecological security barrier in the northwest of China, contributing significantly to biodiversity conservation. However, the ecological environment in the Qilian Mountains is fragile, susceptible to human activities, disturbances, and erosion (Zhao et al., 2016; Niu et al., 2021).The Qilian Mountains feature complex topography, representing a typical semi-arid mountainous ecosystem with elevations ranging from 2000 meters to 3800 meters. The vegetation exhibits distinct vertical zones along the elevation gradient, including grasslands, forest grasslands, subalpine shrubs, and sparse vegetation in high-altitude snow and ice regions (Wan et al., 2019). Until now, there has been limited research comparing the soil ecological stoichiometry of forests, shrubs, and grasslands in the Qilian Mountains, and most studies have been conducted over a one-month period.The study area focuses on a tributary of the Binggou River in the Ice Gully basin, which is located in the upper reaches of the Shiyang River. Therefore, this paper selects Quanshui River, a tributary of Binggou River, as the research object. The research covers a continuous six-month period in a year, analyzing the differences in soil carbon, nitrogen, and phosphorus content, as well as ecological stoichiometry, between forests, shrubs, and grasslands. The aim is to provide appropriate

ISSN 2616-5872 Vol.6, Issue 1: 96-108, DOI: 10.25236/AJEE.2024.060114

recommendations for subsequent governance measures.

2. Materials and Methods

2.1 Description of the Study Area

The Binggou River basin is located in the upper reaches of the Shiyang River, ranging from approximately 102°10'7" to 102°31'52" E longitude and 37°34'7" to 37°47'51" N latitude (Fig. 1). The watershed has a well-developed water system, with most rivers flowing from southwest to northeast, eventually converging into the Nanying Reservoir, resulting in a total basin area of 326 km². The topography slopes from the southwest to the northeast, with most areas situated at elevations above 2000m and a maximum elevation difference of up to 2808m.The climate in the research area falls under a temperate continental climate, characterized by cold and prolonged winters, cool summers, and short spring and autumn seasons. The annual average temperature is 3.5°C, with an annual precipitation of 500mm and evaporation of 800mm. There is significant temperature variation throughout the year, with January being the coldest (average temperature of -10.6°C) and July the hottest (average temperature of 18.2°C) (Zhou et al., 2019; Xiang, 2021).Precipitation shows distinct seasonal variations, primarily concentrated in the summer months. For instance, precipitation in July and August alone can account for more than half of the annual total. Moving from the downstream to the upstream of the basin, the surface cover types transition from desert to grassland, forest, alpine meadow, and alpine desert, corresponding to soil types such as mountain gray-cinnamon soil, mountain chestnut-cinnamon soil, mountain gray-brown soil, and meadow soil, respectively (Niu et al., 2013).The soil is relatively fertile with good moisture conditions. From an elevation of 2500-2700m, the area is covered by grassland, dominated by the IrisensataThunb species. At an elevation of 2700-2900m, the landscape transitions to forest, with prevalent species being Juniperus przewalskii Kom. (Qilian juniper) and Picea crassifolia (Qinghai spruce), where Qinghai spruce is the dominant species. Moving further up to an elevation of 2900-3000m, the vegetation shifts to shrubs, mainly featuring Potentilla fruticosa (cinquefoil) as the primary species[18-29].

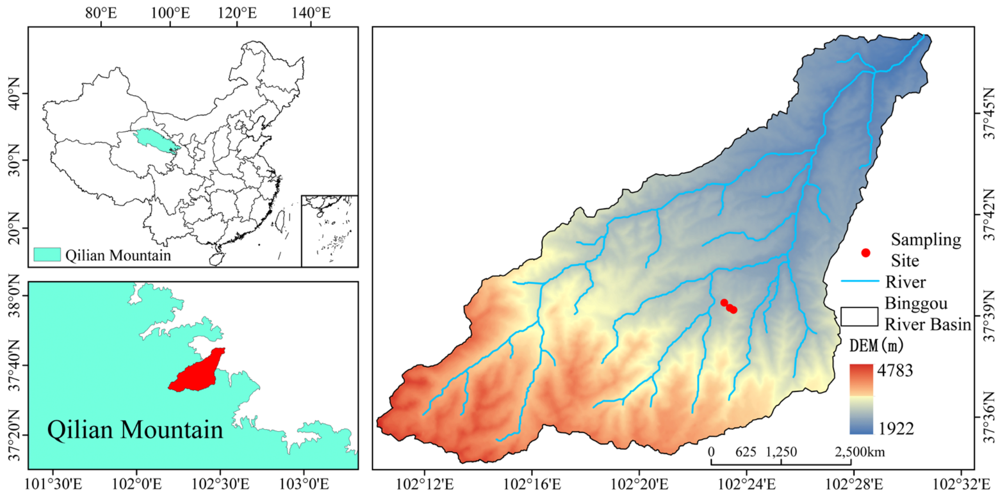

Figure 1: Overview of the Study Area

2.2 Soil sampling and analyses

From May to October 2019, three representative experimental zones were selected within the watershed, each corresponding to three different land types (grassland, shrubland, and forest) featuring Iris ensata Thunb, Potentilla fruticosa, and Picea crassifolia, respectively. Within each experimental zone, three random subplots were chosen. Using the S-shaped sampling method, five representative sampling points were selected within each subplot. Soil samples were collected from different layers (0-10cm, 10-20cm, 20-30cm, 30-40cm, 40-50cm, 50-60cm) using a soil auger, and soils from the same layer were mixed to form a composite soil sample.

In the laboratory, plant residues, fine roots, and gravel were manually removed from the soil samples and air-dried at room temperature for two weeks. The dried soil samples were ground and

ISSN 2616-5872 Vol.6, Issue 1: 96-108, DOI: 10.25236/AJEE.2024.060114

sieved through a 0.25mm mesh to determine soil weight percentages of organic carbon (w(SOC)), total nitrogen (w(TN)), and total phosphorus (w(TP)). The soil w(SOC) was measured using the potassium dichromate external heating method, w(TN) was determined by concentrated sulfuric acid digestion followed by the Kjeldahl method, and w(TP) was analyzed using a perchloric acid-sulfuric acid digestion method (H2SO4 - HClO4) followed by the molybdenum-antimony anti-colorimetric method. Finally, the soil TN and TP contents were measured using the Smartchem200 fully automatic discrete chemical analyzer.

During the sampling period, meteorological elements such as temperature and precipitation at the sampling points were monitored using an automatic weather station (Spectrum WatchDog 2000, Elize, USA) installed within the watershed. The recording interval was set at 15 minutes. Daily average temperature and total daily precipitation data for the sampling points were calculated based on the collected information.

2.3 Statistical analysis

Data collection and analysis were performed using Excel 2010 and SPSS 23, and graphical representations were created using Origin2018 (Origin Lab Inc., Washington, USA). Descriptive statistical methods were employed to analyze the variations in soil SOC, TN, and TP content. The Spearman correlation coefficient was used for correlational analysis of overall soil nutrient levels and their stoichiometric ratios.

3. Results

3.1 The temporal charateristics of soil C, N, P, and their ecological stoichiometry across different vegetation types

The trends in soil SOC and TN content in shrubland exhibit similar patterns, both showing a decline from May to July and an increase from August to October. Grassland's SOC and TN content display strong consistency from May to September, exhibiting a 'U'-shaped variation. Meanwhile, the trends in soil SOC and TN content in the forest, except for June to August, are consistent, with opposite trends observed from June to August (Fig 2)

Considering different vegetation types, the overall soil SOC content in shrubland is higher than in forest and grassland, with grassland exhibiting the lowest SOC content. Notably, from May to July, there is a significant decrease in soil SOC content in grassland. The soil TN content in grassland is significantly higher than in shrubland and forest, displaying an overall 'U'-shaped variation. The soil TN content in the forest, except for being lower than shrubland in May, is higher than shrubland for the remaining five months, with a trend similar to shrubland. Similarly, the soil TP content in grassland is higher than in shrubland and forest, while the difference in TP content between shrubland and forest is minimal (Fig 2).

In summary, shrubland has the highest soil SOC content, while grassland has the lowest SOC content. This indicates that in the study area, shrubland dominated by Potentilla fruticosa exhibits relatively strong carbon sequestration capability, whereas grassland dominated by Iris ensata Thunb has relatively lower carbon sequestration capacity. The soil TN and TP content in grassland are the highest among the three vegetation types, suggesting that grassland has a relatively strong capacity for nitrogen fixation and phosphorus enrichment[30-37].

The differences in soil C:N:P ratios are significant among different vegetation cover types. The overall soil C:N ratio shows the following pattern across the three vegetation types: shrubland > forest > grassland. In shrubland, the soil C:N ratio is at its minimum in spring (May) and reaches its maximum in June. Despite a decrease in soil SOC and TN content in June, the reduction in TN is greater than that of SOC, resulting in a higher C:N ratio. As grassland has the lowest soil SOC content and the highest TN content among the three vegetation types, the C:N ratio in grassland is the smallest compared to the other two types (Fig 3).

The soil C:P ratio in shrubland is overall greater than in forest and grassland, reaching its maximum in spring (May) and its minimum in July and August during the summer. This is attributed to the maximum soil SOC content in shrubland in spring and the relatively smaller SOC content in summer, while the overall variation in soil TP content in shrubland is relatively small. In the forest, the soil SOC gradually increases at the end of summer (August and September), and TP content remains relatively

ISSN 2616-5872 Vol.6, Issue 1: 96-108, DOI: 10.25236/AJEE.2024.060114

stable. Consequently, the C:P ratio in forest soil is higher than in shrubland and grassland. The trend in soil C:P ratio in grassland is roughly similar to that in shrubland, as grassland has the highest TP content and the smallest SOC content among the three vegetation types, resulting in the smallest C:P ratio (Fig 3).

The soil N:P ratio in grassland is significantly higher than in shrubland and forest during spring and autumn, with larger ratios observed at the end of summer and in autumn. Shrubland's soil TN content is lower than in forest in May, while the TP content is overall higher than in forest. Therefore, the soil N:P ratio in shrubland, except for May, is consistently lower than in forest.

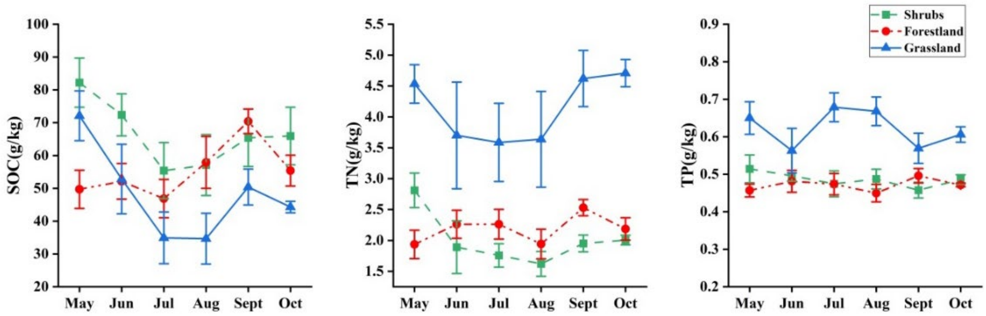

Figure 2: The temporal distribution changes of C,N ,P across different vegetation types in the upper reaches of the Shiyang River.

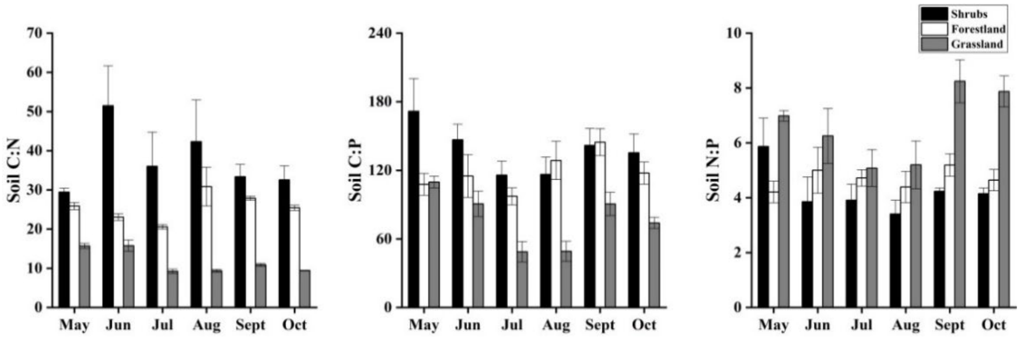

Figure 3: The temporal distribution changes of soil ecological stoichiometry ratios across different vegetation types in the upper reaches of the Shiyang River.

3.2 The vertical characteristics of soil C, N, P, and their ecological stoichiometry ratios across different vegetation types

As shown in Fig 4, the soil SOC content in forest, grassland, and shrubland gradually decreases with increasing soil depth. Across the entire soil profile, the soil SOC levels for the three vegetation types follow the order: shrubland > forest > grassland, and within the 0-30cm soil layer, shrubland exhibits a faster decline in SOC compared to forest and grassland (Tab 1). In the 0-60cm soil layer, the soil TN content decreases gradually for grassland and forest, with grassland having higher TN content than forest and shrubland. Within the 0-40cm soil layer, grassland experiences a greater decline rate compared to forest and shrubland (Tab 1). In the 30-60cm soil layer, the TN decline rate for shrubland is negative, indicating an increase in soil TN content, which is contrary to the trends observed in forest and grassland. Similarly, throughout the entire soil profile, the soil TP content in grassland is higher than in forest and shrubland, while the difference in TP content between forest and shrubland is minimal[38-43].

Due to the soil SOC content being highest in shrubland and relatively lower in TN compared to the other two vegetation types, while grassland has the minimum SOC content and the highest TN content, the soil C:N ratio for the three vegetation types appears in the order: shrubland > forest > grassland. The soil C:P ratio for shrubland and forest shows minimal difference within the 0-60cm soil layer, while grassland has the smallest C:P ratio. This is attributed to similar soil TP content in shrubland and forest, with grassland having higher TP content than forest and shrubland. The soil N:P ratio in grassland is higher than in forest and shrubland, as grassland's soil TN and TP content are both higher than the other two vegetation types, resulting in this pattern (Fig. 5).

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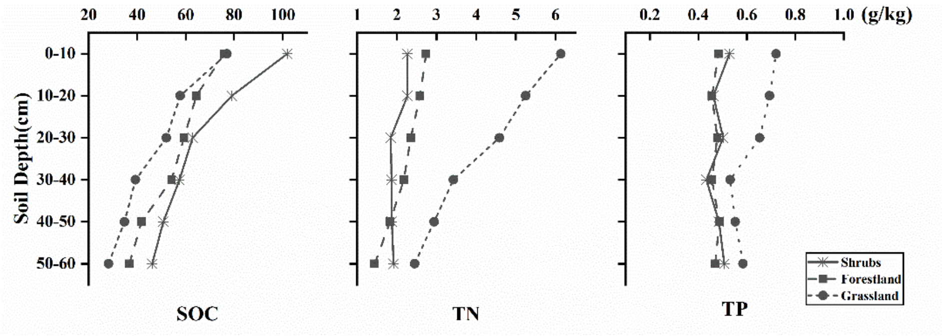

Figure 4: The vertical distribution changes of soil SOC, TN, and TP in different vegetation types in the upper reaches of the Shi Yang River.

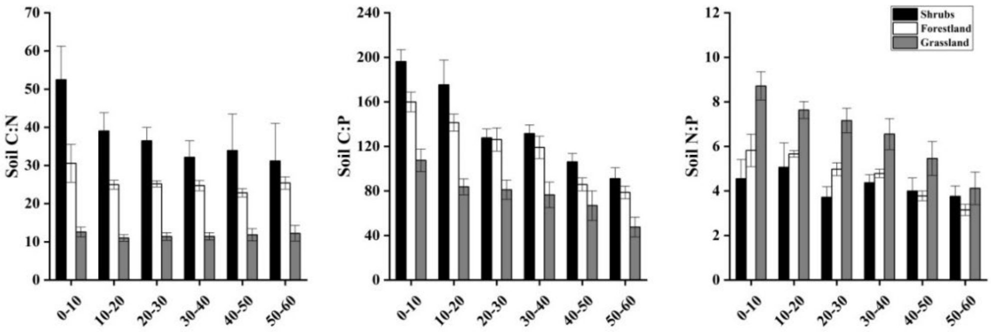

Figure 5: The vertical profile distribution changes of soil ecological stoichiometry ratios in different vegetation types in the upper reaches of the Shi Yang River.

Table 1: Vertical Profile Decline Rates of Soil SOC, TN, and TP Contents in Different Vegetation Types.

Item	Soil layer	Forestland	Grassland	Shrubs
SOC	0-10~10-20	0.151632	0.25008	0.224771
	10-20~20-30	0.078256	0.099179	0.203558
	20-30~30-40	0.086573	0.244706	0.087125
	30-40~40-50	0.228342	0.116211	0.115147
	40-50~50-60	0.121001	0.187517	0.090697
TN	0-10~10-20	0.05572	0.144356	0.001387
	10-20~20-30	0.089212	0.125515	0.185784
	20-30~30-40	0.075565	0.253238	-0.01283
	30-40~40-50	0.158757	0.142079	-0.0033
	40-50~50-60	0.212498	0.16581	-0.02364
TP	0-10~10-20	0.054965	0.036992	0.124566
	10-20~20-30	-0.04779	0.058652	-0.08731
	20-30~30-40	0.046862	0.187144	0.138563
	30-40~40-50	-0.06877	-0.04149	-0.11941
	40-50~50-60	0.036692	-0.05615	-0.04611

3.3 The correlation of soil ecological stoichiometry ratios

The contents of SOC, TN, and TP in the soil are closely correlated with their stoichiometric ratios (Tab 2). SOC is positively correlated with TN and TP, with correlation coefficients of 0.305 and 0.025, respectively. TN and TP also show a positive correlation with a correlation coefficient of 0.463. C:N and C:P ratios, as well as C:N and N:P ratios, reached significant levels with correlation coefficients of 0.739 and -0.468, respectively.

In the shrubland soils, SOC showed no significant linear relationship with TN, TP, and C:P (Carbon to Phosphorus) ($p > 0.05$). However, SOC exhibited a significant positive correlation with C:N and C:P ($p < 0.01$), while TN had a significant negative correlation with C:N ($p < 0.01$) and a significant positive correlation with N:P ($p < 0.01$). TP showed a significant negative correlation with N:P ($p < 0.05$) in this context.In forested soils, SOC was significantly positively correlated with TN, C:N, C:P, and N:P ($p < 0.01$). TN also showed significant positive correlations with C:P and N:P ($p < 0.01$), while TN and TP exhibited no significant linear relationship with C:N ($p > 0.05$).In grassland soils, SOC demonstrated significant positive correlations with TN, C:N, C:P ($p < 0.01$), and a significant positive correlation with TP ($p < 0.05$). TN had significant positive correlations with C:P and N:P ($p < 0.01$) but showed no significant linear relationship with C:N ($p > 0.05$).

Among the three vegetation types, there is not a strong correlation between soil nutrients in shrubland soils. In forested soils, SOC and TN are significantly positively correlated. In grassland soils, there are significant positive correlations among soil nutrients, especially a highly significant positive correlation between SOC and TP. This suggests that the degree of mutual influence among soil nutrients in shrubland soils is relatively lower compared to the other two vegetation types, while in grassland soils, there is a stronger mutual influence among soil nutrients.Due to the varying degrees of correlation and mutual influence among soil nutrients in the three vegetation types, this also leads to significant differences in their nutrient contents[44-52].

Table 2: The correlation coefficients between soil stoichiometry under different vegetation cover types.

Type	Item	SOC	STN	STP	RCN	RCP	RNP
Shrubs	SOC	1.000					
	STN	0.319	1.000				
	STP	0.171	0.021	1.000			
	RCN	0.543*	-0.553*	0.220	1.000		
	RCP	0.913*	0.274	-0.176	0.488*	1.000	
	RNP	0.184	0.864*	-0.400**	-0.601	0.326	1.000
Forestland	SOC	1.000					
	STN	0.778*	1.000				
	STP	0.137	0.049	1.000			
	RCN	0.563*	0.085	0.150	1.000		
	RCP	0.937*	0.778*	-0.164	0.488*	1.000	
	RNP	0.738*	0.934*	0.269	0.087	0.838*	1.000
Grassland	SOC	1.000					
	STN	0.857*	1.000				
	STP	0.418**	0.507*	1.000			
	RCN	0.566*	0.161	-0.022	1.000		
	RCP	0.848*	0.612*	-0.047	0.714*	1.000	
	RNP	0.729*	0.829*	0.006	0.193	0.743*	1.000
All types	SOC	1.000					
	STN	0.305*	1.000				
	STP	0.025	0.463*	1.000			
	RCN	0.558*	-0.545*	-0.444*	1.000		
	RCP	0.874*	0.007	-0.423*	0.739*	1.000	
	RNP	0.311*	0.923*	0.145	-0.468*	0.148	1.000

* Correlation is significant at the 0.01 level (2-tailed).
** Correlation is significant at the 0.05 level (2-tailed).

4. Discussion

4.1 Characteristics of soil nutrients and their ecological stoichiometry ratios under different vegetation types

The differences in soil C and N content were significant among different vegetation types, and they were also influenced significantly by soil depth. In all three vegetation types, soil SOC and TN content decreased with increasing soil depth, which is consistent with the findings of many previous studies (Zhang et al., 2019; Zeng et al., 2015; Li et al., 2014; Sayer, 2006). Since the primary sources of soil organic matter are soil litter and surface plant litter, and they play a crucial role in promoting nutrient cycling within the soil (García-Palacios et al., 2016), the highest SOC and TN content is found in the surface soil layer.

Jobbagy and Jackson (2000) found that vegetation type significantly influences soil SOC content. In shrubland soils, SOC content is primarily distributed in the lower portion of the upper layer, in grasslands, it mainly occurs in the middle layer of the soil, and in forests, it predominantly resides in the surface layer of the soil. Shrubland and forest soils contain a substantial amount of SOC, while grassland soils have lower SOC content. This is mainly due to higher productivity in forests and shrublands, resulting in more plant litter and organic matter input, whereas grasslands have lower vegetation productivity and less organic matter input. Additionally, the woody content in shrub and forest litter is higher than that in herbaceous plant litter, leading to more stable soil organic matter. Furthermore, the higher elevations of forests and shrublands result in lower temperatures, slower organic matter decomposition, and the formation of a grass mat crust on the surface (Jackson et al., 2000).

Soil nitrogen primarily originates from the decomposition of vegetation litter, nitrogen fixation by leguminous plants, and atmospheric nitrogen deposition. Due to differences in vegetation types and their varying nitrogen requirements, the efficiency of nitrogen utilization also differs. Therefore, changes in vegetation type can influence soil nitrogen content (Lo and Lo, 2005; Pei et al., 2008; Li et al., 2020; Pang et al., 2015).In this study, the soil TN content in grassland was significantly higher than that in shrubland and forests. Typically, forests and shrublands have richer species diversity compared to grasslands. These plants have faster growth rates and tend to absorb more nitrogen from the soil. Additionally, forests and shrublands are located at higher elevations relative to grasslands, resulting in lower temperatures and slower organic matter decomposition rates. As a result, soil TN content in forests and shrublands tends to be relatively lower, while in grasslands, organic matter decomposition is relatively faster, leading to the release of a substantial amount of nitrogen into the soil.Soil TP content showed relatively small differences among the three vegetation types because phosphorus is a mineral element with low mobility (Zhang et al., 2019). Its content primarily depends on the geological characteristics of the site (Wang et al., 2004).

Soil stoichiometry is a necessary indicator for determining soil nutrient cycling and provides a comprehensive nutrient framework on a global scale (Liu et al., 2016). In this study, the C:N, C:P, and N:P ratios in the surface soil were higher than those in the deeper soil layers, consistent with the findings of Wang et al. (2022)[53-58].

The soil C:N ratio is an important indicator for assessing the balance between carbon and nitrogen in the soil. It reflects the decomposition rate of organic matter by soil microorganisms. When the C:N ratio is between 15-25, soil assimilation and mineralization are in balance. A higher C:N ratio indicates slower rates of organic matter decomposition and soil mineralization in the region (He et al., 2020). When the C:N ratio is less than 15, soil mineralization dominates over assimilation, accelerating organic matter decomposition, and microorganisms no longer utilize available nitrogen in the soil, removing nitrogen limitations on vegetation growth.In this study, due to the higher accumulation and slower decomposition rates of organic matter in forested and shrubland soils compared to grassland soils, the soil SOC content was higher in the former. Grassland soils, on the other hand, had higher soil TN content than forested and shrubland soils, resulting in higher C:N ratios in forested and shrubland soils compared to grassland.In the 0-60cm soil layer, the soil C:N ratios for forested and shrubland were 25.6043 and 37.5339, indicating slow rates of organic matter decomposition and mineralization, which favor organic matter accumulation. The C:N ratio for grassland was 11.7312, signifying faster rates of organic matter decomposition and mineralization, which hinder organic matter accumulation.In this research, there was a significant negative correlation between soil TN and the C:N ratio, and the soil nitrogen content in the study area's forests and shrublands was slightly deficient, resulting in higher C:N ratios in the soil, all of which were higher than the national average (11.9)(Tab.3).

The soil C:P ratio can be used to assess the mineralization potential of soil microorganisms for releasing phosphorus from organic matter and their ability to absorb and convert external phosphorus, reflecting soil phosphorus mineralization capacity and effectiveness (He et al., 2020; Hessen et al., 2004). In the study area, the soil C:P ratios for the three vegetation types in the 0-60cm soil layer were as follows: shrubland > forest > grassland. This result is due to the non-significant differences in soil TP content among the three vegetation types, with shrubland having the highest soil SOC content, followed by forest, and grassland having the lowest. Additionally, the soil C:P ratios for all three vegetation types in the study area were higher than the national average (61). A higher C:P ratio indicates lower phosphorus effectiveness in the soil, slower phosphorus mineralization rates, and susceptibility to phosphorus limitations during microbial decomposition processes (He et al., 2020).Since vegetation continually decomposes soil organic matter during its growth, carbon elements in the soil are replenished to some extent while being consumed (Zarei et al., 2021). However, phosphorus elements are consumed, but the phosphorus released by microorganisms is lower compared to the release of carbon and nitrogen elements. In this study, soil TP showed a significant negative

ISSN 2616-5872 Vol.6, Issue 1: 96-108, DOI: 10.25236/AJEE.2024.060114

correlation with the C:P ratio, indicating that the soil C:P ratios in various vegetation types in the study area are relatively high.

The N:P ratio can serve as an effective indicator for determining nutrient limitations and is also an important measure for assessing soil nitrogen saturation status (Zeng et al., 2017). Among the three vegetation types, due to the relatively similar soil TP content across all three types and significantly higher soil TN content in grassland compared to the other two types, the N:P ratio is highest in grassland. The differences in N:P ratios between forest and shrubland are not significant, and only the N:P ratio in grassland soil exceeds the national average (5.2).Typically, an N:P ratio less than 14 indicates nitrogen limitation (Tessier and Rayonal, 2003), suggesting that the region is limited by soil nitrogen. In this study, there was a significant positive correlation between soil TN and N:P ratios, further indicating the deficiency of soil nitrogen elements in various vegetation types in the study area, especially in forests and shrublands.

In this study, the soil C:N ratio and C:P ratio in shrubland were significantly higher than those in forest and grassland, while the N:P ratio was slightly lower. This indicates that shrubland and forest are more effective at carbon sequestration compared to grassland, but forest and grassland are more conducive to soil nitrogen retention. The higher microbial biomass and greater presence of woody debris in forested soils, along with suitable grazing activities in grasslands, contribute to the accumulation of soil nitrogen.Additionally, in this study, significant negative correlations were observed between TN and C:N, as well as between TP and C:P ratios, indicating that soil nitrogen and phosphorus elements primarily influence the soil nutrient stoichiometry characteristics and processes in the Quan Shui River, a tributary of the Bingou River Basin. Furthermore, the results of soil C:N:P stoichiometric ratios suggest that the degree of limitation by soil nitrogen and phosphorus elements during vegetation growth in the study area is specific, with nitrogen being more limiting than phosphorus (N > P).

Table 3: The Average Soil Ecological Stoichiometry Ratios in Three Different Vegetation Types

Item	Forestland	Grassland	Shrubs	China
SOC	55.4022	48.1993	66.4057	-
TN	2.1866	4.1314	2.0066	-
TP	0.4714	0.6225	0.4860	-
RCN	25.6043	11.7312	37.5339	11.9
RCP	118.4358	77.1586	137.9531	61
RNP	4.6918	6.6046	4.2395	5.2
Reference	-	-	-	(Tian et al.,2010)

4.2 The response of soils in different vegetation types to climate change

Due to differences in vegetation types, their responses to changes in temperature and precipitation also vary, subsequently influencing soil microbial activities and leading to different changes in soil nutrient content. Temperature affects plant growth and the microbial degradation of organic matter. Generally, below 0°C, the rate of organic matter decomposition in soil is minimal. In the temperature range of 0-35°C, increasing temperatures promote organic matter decomposition. The optimum temperature range for soil microbial activity is typically around 25-35°C, and microbial activity is significantly inhibited outside of this range. Microbial activity in soil also requires an appropriate soil moisture content, but excessive moisture reduces oxygen levels in the soil, altering the decomposition process and products of soil organic matter (Huang, 2000).

The impact of monthly average temperature and monthly average precipitation on the soil SOC content varies among the three vegetation types (Fig. 6). As temperatures rise, the soil SOC and TN content in grassland decreases most rapidly, followed by shrubland, while the change in soil SOC and TN content in forestland is relatively small. In June and July, when temperatures increase rapidly, soil microbial activity enhances, promoting the mineralization of soil nitrogen and accelerating SOC decomposition, leading to more carbon and nitrogen being released from the soil into the atmosphere, which is unfavorable for SOC and TN accumulation (Ben et al., 2018; Tóth et al., 2007). On the other hand, increased rainfall leads to higher soil moisture, causing soil aggregates to disperse and break apart. This results in the release of previously fixed SOC and TN, providing more nutrients for soil microbial activity, increasing soil respiration rates, and promoting SOC and TN mineralization, which is unfavorable for SOC and TN fixation (Wang et al., 2018).

Conversely, in August, September, and October, lower temperatures and reduced precipitation

ISSN 2616-5872 Vol.6, Issue 1: 96-108, DOI: 10.25236/AJEE.2024.060114

collectively suppress SOC decomposition and nitrogen mineralization processes, favoring the fixation of more carbon and nitrogen in the soil. This leads to higher carbon and nitrogen storage in the winter and lower levels in the summer. Therefore, temperature and precipitation jointly influence the distribution of soil SOC and TN, especially in terms of seasonal variations.

Previous studies have suggested that ecosystems may exhibit inherent characteristics, such as carbon inputs promoting nitrogen accumulation to maintain synchronous changes in carbon and nitrogen (Chen et al., 2016; Luo et al., 2006). Consequently, soil carbon and nitrogen exhibit relatively consistent spatial distribution patterns (Liu et al., 2020). In the study area, the reduction in soil TP content in the three vegetation types is not significant with increasing rainfall. However, Tian et al. (2010) found that increasing rainfall significantly decreased soil TP content. This difference may be due to the semi-arid nature of the study area, as the phosphorus cycle is strongly influenced by temperature and humid climate (Jiao et al., 2016).

In summary, climate change has the greatest impact on soil SOC and TN content changes in grassland, followed by shrubland, and lastly, forestland.

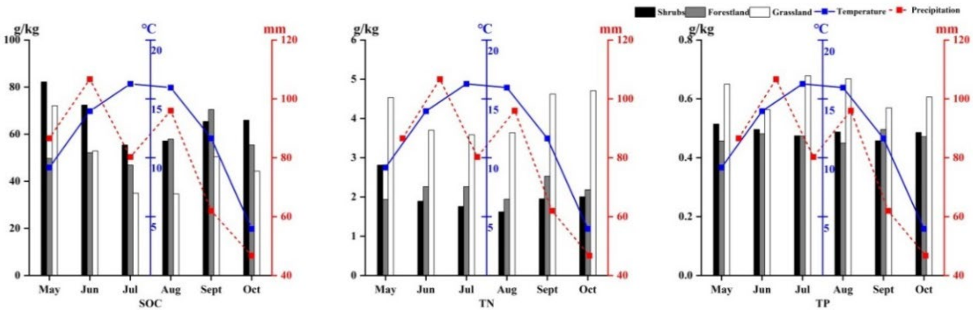

Figure 6: The Relationship between Temperature and Precipitation and Changes in Soil Nutrient Content in Different Vegetation Types

5. Conclusions

This study investigated the impact of three different vegetation types on the soil SOC, TN, TP content, and stoichiometry in the 0-60cm soil layer in the Quan Shui River, a tributary of the Bingou River Basin, in the eastern segment of the Qilian Mountains. The results indicate that in the Quan Shui River region, forest and shrubland have slower soil organic matter decomposition rates, and the effectiveness of phosphorus in the soil is lower in all three vegetation types. Additionally, the degree of limitation by soil nitrogen and phosphorus elements during vegetation growth in this region is characterized by N > P. Vegetation type has a significant impact on soil C, N, P content, and their stoichiometric ratios. Forestland, compared to shrubland and grassland, has advantages in soil nutrient retention. Nitrogen and phosphorus elements primarily influence the soil nutrient stoichiometry characteristics and processes in this region. Therefore, rational nitrogen and phosphorus fertilizer application is recommended to further reduce soil nutrient loss, improve soil fertility, and increase productivity.

Acknowledgements

We thank Professor Zhao Chuanyan of Lanzhou University for reviewing the format, content and graphics of the paper.

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