Postprint: Responses of Plant Elemental Content and Soil Factors to Slope Aspect Gradients in Gannan Alpine Meadows

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Abstract

Through measurements of leaf nitrogen (N), phosphorus (P), and potassium (K) contents, organic carbon (C) content, leaf water content, and relative chlorophyll (SPAD) values of 86 plant species from 25 families, as well as soil indicators including soil water content, organic carbon, total nitrogen, and total phosphorus content under different slope aspect conditions in the Gannan alpine meadow, we analyzed the relationship between plant leaf element content and soil environmental factors across different slope aspects. The results showed that along the south-facing to north-facing slope gradient, with increasing soil water content, plant leaf P content, leaf K content, and leaf water content increased significantly, while relative chlorophyll decreased significantly. Soil nutrient content was significantly positively correlated with plant leaf P content, leaf K content, and leaf water content, and significantly negatively correlated with leaf relative chlorophyll. This indicates that under different slope aspect conditions, leaf nutrient content is significantly influenced by soil factors, and the contributions of soil moisture and nutrient status to plant leaf element content differ. Soil water content is the most important factor affecting plant leaf characteristics on the slope aspect gradient. The influence of soil water content on various plant leaf element contents and the response patterns of leaf water content to different soil factors along the slope aspect gradient support the notion that plants growing on south-facing slopes adapt to the relatively dry and barren habitats of south-facing slopes by improving water and nutrient use efficiency.

Full Text

Preamble

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Response of Plant Element Content and Soil Factors to the Slope Aspect Gradient of Alpine Meadows in Gannan

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Abstract

This study measured nitrogen, phosphorus, potassium, organic carbon, water content, and SPAD values of plant leaves from 25 families and 86 species across different slope aspects of alpine meadows in Gannan, along with soil physicochemical properties including nitrogen, phosphorus, organic carbon, and water content. The objective was to determine variations in plant element content and soil factors at different slope aspects and analyze the relationship between plant leaf nutrient content and soil environmental factors. The results showed that soil factors differed significantly across slope aspects. Specifically, soil phosphorus content decreased successively from northern to southern slopes. Soil nutrient and organic carbon content on northern slopes were much higher than those on southern slopes, whereas they were lowest on western slopes. Notably, soil water content on northern slopes reached up to 38%, in contrast to slightly lower values on southern slopes. Plant constituents showed meaningful differences at different slope aspects due to variation in soil factors. Leaf organic carbon content exhibited little distinct change across slopes, while leaf nutrient content and SPAD values increased from northern to southern slopes. In contrast, leaf phosphorus, potassium, and water content decreased. Soil factors had significant effects on foliar traits along the south-north slope gradient. Increased soil water content enhanced leaf phosphorus, potassium, and water content in plant leaves, while significantly decreasing SPAD values. Soil water content was significantly positively correlated with plant leaf phosphorus, potassium, and water contents, but negatively correlated with SPAD. The contribution of soil water content and nutrients to leaf element content differed. We concluded that soil water content was the primary factor affecting foliar characteristics and that leaf water content was particularly influenced by environmental factors at different slopes. The response pattern of leaf water content in southern slope plants to soil conditions reinforces that improved water and nutrient use efficiency is an adaptive strategy to drought and barren habitats on southern slopes.

Keywords: alpine meadow; leaf element content; leaf water content; SPAD; soil factors

1. Introduction

The relationship between plants and their environment represents a critical focus of global ecological research. Plant growth is constrained not only by topographic environmental factors but also by the physiological condition of the plants themselves, with these influences reflected through leaf characteristics. As the basic structural and functional unit of terrestrial ecosystems, leaves contain essential nutrient elements (C, N, P, K) that play vital roles in plant constitution and physiological metabolism. Because these biochemical components in plant leaves are relatively stable and their interrelationships follow similar patterns across various plant populations and communities, leaf nutrient composition has become a key indicator for scaling studies from the leaf level to entire communities, regions, or global biogeographic zones. Strengthening research on leaf trait patterns provides a scientific basis for coupling chemical cycle models with vegetation geography models and helps mechanistically explain regional vegetation adaptation and response mechanisms to global change.

Many studies have demonstrated that N/P ratios exhibit significant regular changes with climatic factors at global or large regional scales. However, research on leaf traits at micro-topographic scales remains scarce. The Qinghai-Tibet Plateau, with its unique geographic unit and distinctive climate characteristics, has long been considered a sensitive region to climate change. Intensifying global change will inevitably impact plant species and communities in the alpine meadow ecosystems of the Qinghai-Tibet Plateau, while conversely, the dynamic changes in plant species and ecosystem structure and function can sensitively reflect global climate variations. Alpine meadow vegetation exhibits typical alpine climate characteristics, and long-term natural selection has enabled plants in this region to develop unique mechanisms for adapting to environmental stress. While relevant studies on nutrient variation characteristics of alpine meadow plants have been conducted with some achievements, comprehensive research at micro-topographic scales considering elements including C, N, P, and K remains unreported.

Therefore, this study attempts to analyze plant leaf C, N, P, K, relative water content, and relative chlorophyll (SPAD) in response to environmental factors under different slope aspect conditions, exploring the effects of different slope aspect environments and stress conditions on the physiological and ecological characteristics of alpine meadow plants. The objectives are to provide data for comprehensively studying the relationship between biogeochemical cycles of important life elements and global change in China' s terrestrial ecosystems, supplement data for regional vegetation dynamic models, and ultimately enrich global-scale vegetation-climate relationship databases.

2. Study Area

The experimental site is located near Dangzhougou in Gannan Tibetan Autonomous Prefecture, Gansu Province, with geographic coordinates of 34°56 N, 102°54 E and an elevation of 3005 m. The mean annual temperature is -8.8°C, with a mean July temperature of 11.6°C. The annual accumulated temperature is 1732°C, and mean annual precipitation is 559.5 mm. The vegetation belongs to the sub-alpine meadow type. Dominant plant species in the sample plots include *Gentiana macrophylla*, *Stellera chamaejasme*, *Medicago sativa*, *Oxytropis ochrocephala*, *Potentilla anserina*, *Elymus nutans*, *Polygonum viviparum*, *Potentilla fruticosa*, *Aristida triseta*, *Taraxacum mongolicum*, and *Kobresia humilis*. The soil is classified as sub-alpine meadow soil.

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3. Experimental Design

We selected a mountain with distinct north-south slope differentiation near Dangzhougou and determined slope aspects using a compass. Study plots were established at the upper, middle, and lower positions of the mountain slope, with each plot separated by 20-30 m. Aboveground biomass was harvested in early August. Soil samples were collected using a 50 cm × 50 cm auger at two depths (0-20 cm and 20-40 cm) within each quadrat, mixed, and placed in aluminum boxes for subsequent water and nutrient measurements. The plot layout is shown in [Figure 1: see original paper].

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4. Plant and Soil Sample Analysis

Plant carbon content was determined using the H_2SO_4-H_2O_2 digestion method with $K_2Cr_2O_7$ oxidation and external heating. Nitrogen content was measured using the micro-Kjeldahl method, phosphorus by molybdenum-antimony colorimetry, and potassium by flame photometry. Plant water content was determined by oven drying and weighing. Leaf relative chlorophyll was measured using a portable chlorophyll meter (SPAD-502, Minolta Camera Co., Osaka, Japan) on the same species and replicates used for photosynthetic measurements. The SPAD-502 calculates values based on the transmittance of light at 650 nm and 940 nm wavelengths, providing a relative measure of chlorophyll content.

Soil organic carbon was determined by the $K_2Cr_2O_7$ capacity method. Soil total nitrogen was measured using the H_2SO_4-K_2SO_4-$CuSO_4$-Se catalytic digestion method followed by titration with ferrous sulfate after $K_2Cr_2O_7$ digestion. Soil total phosphorus was determined by the molybdenum-antimony method. Soil water content was measured by the oven-drying method using the formula: SWC = (mass_f - mass_d) / mass_f, where mass_f is fresh mass and mass_d is dry mass.

5. Data Processing

Statistical analyses were performed using Excel 2007 and SPSS 18.0 software. One-way ANOVA was used to analyze differences among slope aspects, and Pearson correlation analysis was conducted to examine relationships between variables. SigmaPlot 10.0 was used for graphical presentations. Significance was set at $p < 0.05$.

6. Results and Analysis

6.1 Soil Nutrients and Water Content Across Slope Aspects

Soil water content (SWC) in the 0-20 cm layer showed significant differences among slope aspects, with the highest values on north slopes (38%) and significantly lower values on southern slopes. SWC in the 20-40 cm layer followed similar trends but with lower values than the surface layer. Soil total phosphorus (TP) content decreased successively from north to southwest to south slopes, with significant differences between north and south slopes. Soil total nitrogen (TN) and organic carbon (SOC) content were significantly higher on north slopes compared to south slopes, but lowest on west slopes. Significant differences were found between north and northwest slopes versus southwest and south slopes for TN, and between north and south slopes for SOC. The surface soil (0-20 cm) showed nutrient enrichment compared to the deeper layer (20-40 cm), with higher TN and SOC content across all slope aspects.

6.2 Species Composition and Community Structure Changes Across Slope Aspects

Plant community structure and species composition changed substantially across slope aspects. North slopes were dominated by *Potentilla fruticosa* shrubland with associated forbs. Northwest slopes featured *Potentilla fruticosa* with *Polygonum viviparum* as a codominant species. West slopes had *Medicago sativa* as a dominant species, while southwest slopes showed fewer species. South slopes were characterized by graminoid species such as *Kobresia humilis* and *Aristida triseta*, along with some legume species. Species richness, Shannon diversity index, vegetation coverage, and biomass all decreased progressively from north to south slopes .

6.3 Changes in Plant Leaf Element Content and Relative Chlorophyll Across the Slope Aspect Gradient

At the community level, leaf organic carbon content showed no significant differences across the slope aspect gradient. Leaf nitrogen content and SPAD values increased from north to south slopes, with significant differences in leaf nitrogen between north and south slopes and significant differences in SPAD among all slope aspects. In contrast, leaf phosphorus, potassium, and relative water content decreased along the north-south gradient. Leaf phosphorus and potassium contents were significantly different between north and south slopes, while leaf relative water content was highest on shady slopes (9.87%) and lowest on sunny slopes (2.42%), with significant differences between north and northwest slopes versus west, southwest, and south slopes [FIGURE:2, FIGURE:3].

6.4 Correlations Between Soil Factors and Plant Leaf Characteristics

In the 0-20 cm soil layer, soil water content showed significant positive correlations with leaf phosphorus, potassium, and water content ($p < 0.001$), but significant negative correlations with SPAD values ($p < 0.001$). Soil total phosphorus content was significantly positively correlated with leaf phosphorus, potassium, and water content ($p < 0.001$), but negatively correlated with SPAD ($p = 0.001$). Soil organic carbon content was significantly positively correlated with leaf phosphorus, potassium, and water content ($p < 0.0001$), but negatively correlated with SPAD ($p = 0.001$). However, soil total nitrogen content showed no significant correlations with leaf nutrient or water content, indicating that soil nitrogen content does not directly influence leaf nutrient absorption in this system.

6.5 Effects of Soil Factors on Plant Leaf Characteristics

Soil water content had significant effects on leaf phosphorus, potassium, and water content, with these parameters showing significant increasing trends as soil water content increased ($p < 0.0001$). Leaf water content was also significantly positively correlated with soil water content ($p < 0.001$), indicating that improved soil moisture conditions in alpine meadows favor higher leaf water retention. Conversely, soil water content was significantly negatively correlated with relative chlorophyll content (SPAD), suggesting that leaf chlorophyll content is strongly influenced by soil moisture variation. Soil total nitrogen was not directly related to changes in leaf nutrient content or relative water content. Soil organic carbon and total phosphorus showed similar influence patterns to soil water content, being significantly positively correlated with leaf phosphorus, potassium, and water content, but negatively correlated with SPAD.

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7. Discussion

Terrain represents a fundamental factor shaping ecological processes and influences the distribution of abiotic resources such as light radiation, temperature, humidity, and soil nutrients. The effects of topography on plant distribution in communities primarily concentrate on slope gradient and aspect, which alter soil conditions and create unique microclimates that indirectly affect the quantity and distribution of soil moisture and nutrients. Our results demonstrate that north slopes possess higher soil water and nutrient resources compared to south slopes, leading to substantial changes in species composition and community structure. South slopes are dominated by stress-resistant graminoid species, while north slopes support shrubland communities of *Potentilla fruticosa* with various forbs. This pattern aligns with De Bello et al.' s findings in temperate grasslands, where species richness and diversity indices increased along aridity-moisture gradients, reaching maximum values in the wettest habitats. This is because species diversity and richness are generally determined by resource availability.

Carbon, nitrogen, phosphorus, and potassium constitute essential elements of the biological world. As primary components of carbohydrates, proteins, nucleic acids, chlorophyll, and enzymes, they play crucial roles in plant structure, photosynthesis, and stress resistance. Plant nutrient elements are primarily absorbed from soil through root systems, making soil water content and nutrient status major factors influencing nutrient uptake. In the alpine meadow region, soil moisture is the key limiting factor for plant growth, vegetation community development, and ecosystem stability along slope aspect gradients.

Our findings show that soil water content is the most critical factor affecting leaf nutrient content, water content, and relative chlorophyll across the slope aspect gradient. The response pattern of leaf water content to different soil factors supports the hypothesis that plants on south slopes adapt to drier and more barren habitats by improving water and nutrient use efficiency. While soil nutrient content (particularly phosphorus and organic carbon) significantly influences leaf characteristics, the correlation coefficients indicate that soil water content exerts the strongest control. The contrasting responses of different plant species to soil moisture likely reflect their distinct genetic and ecophysiological characteristics. The significant relationship between soil phosphorus and leaf traits, compared to the lack of correlation with soil nitrogen, suggests complex nutrient limitation patterns in these alpine meadow ecosystems.

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Note: Figure translations are in progress. See original paper for figures.