Analysis of Soil Driving Forces Affecting Quantitative Characteristics of Desert Plants in the Fukang Desert-Oasis Ecotone: Postprint

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Date: 2018-01-09T00:00:00+00:00

Abstract

The desert-oasis ecotone represents a transitional zone from oasis to desert systems, wherein desert plants function as a buffer against oasis expansion or accelerated desertification. Soil environment constitutes a critical factor influencing plant evolution, with soil environmental factors serving as important driving forces for the evolution of the entire ecotone. Through field investigation of desert plant communities in the Fukang desert-oasis ecotone and redundancy analysis (RDA) conducted using the universal plant quantitative analysis software CANOCO 5.0, this study explores the soil driving factors influencing the quantitative characteristic indicators of desert plant communities in the ecotone. The results demonstrate: (1) Soil water content, total N, total P, and organic matter represent the primary driving factors affecting the quantitative characteristics of desert plant communities, with a cumulative environmental interpretation of 69%, whereas total salt, pH, and total K exhibit weaker influences on these characteristics; (2) The order of importance among the four main soil driving forces on the quantitative characteristics of desert plant communities is: soil water content > organic matter > total N > total P; (3) The quantitative characteristics of desert plant communities show positive correlations with soil water content, organic matter, and total P, but a negative correlation with total N, revealing that soil water content, organic matter, and total P act as positive driving forces conducive to desert plant community stability, while total N functions as a negative driving force that inhibits desert plant growth. In summary, the driving effects of various soil factors differ, exhibiting positive and negative variations that synergistically maintain the stability and development of the quantitative characteristics of desert plant communities.

Full Text

Driving Forces of Soil on Quantitative Characteristics of Desert Plants in the Fukang Desert-Oasis Ecotone

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Abstract

The desert-oasis ecotone serves as a transitional zone between oasis and desert systems, where desert plants act as buffers against oasis expansion or accelerated desertification. Soil environmental factors not only influence plant evolution but also constitute important driving forces for the entire transition zone. Through field investigation of desert plant communities in the Fukang desert-oasis ecotone, this study examined the soil factors driving quantitative characteristics of desert plant communities. Soil moisture content and organic matter emerged as the primary driving forces affecting desert plant community quantitative characteristics, with their combined environmental explanatory power reaching 69% of the total variation. The order of importance for these four major soil driving factors was: soil moisture > organic matter > total N > total P. Quantitative characteristics of desert plants showed positive correlations with soil moisture, organic matter, and total P, but negative correlations with total N, revealing that soil moisture, organic matter, and total P are positive driving forces favorable to desert plant community stability, while total N acts as a negative driving force inhibiting desert plant growth. These factors synergistically maintain the stability and development of desert plant community quantitative characteristics. Redundancy analysis (RDA) using the commonly employed plant quantitative analysis software CANOCO 5.0 demonstrated that total salt, pH, total K, and plant density had weaker effects on desert plant community quantitative characteristics. The driving effects of soil moisture, organic matter, total N, and total P varied significantly among different factors.

Keywords: plant growth drivers; quantitative features; desert plants; ecotone

Introduction

The fragile Fukang desert-oasis ecotone features diverse and complex ecological environments with strong human disturbance, serving as an interface zone where energy and information frequently exchange between two ecosystems. Investigating the quantitative characteristics of desert plant communities and their influencing factors in this transition zone holds practical significance for maintaining oasis stability. Desert plants include xerophytic or super-xerophytic small trees, shrubs, and herbs that are closely related to their surrounding environment during growth and development, playing crucial roles in curbing desertification. Plant community quantitative characteristics are significantly influenced by soil environmental constraints, which affect plant growth, distribution, and community attributes. Soil moisture leads to patchy plant distribution, and its increase promotes fresh weight gain in desert plant leaves. Soil salt content not only alters distribution patterns of desert plant species but also affects leaf size and quality. Increased soil spatial heterogeneity, particularly in soil organic matter, further influences differentiation in plant community quantitative characteristics. Dune size, climate, and the coupling of comprehensive natural factors with soil all represent important factors affecting desert plant community quantitative characteristics.

While relationships between desert plant community quantitative characteristics and soil factors are critical for management and vegetation restoration in desert-oasis ecotones, previous research has primarily focused on physiological responses of desert plants to individual soil factors such as water, salt, and organic matter, with fewer studies simultaneously considering the combined effects of multiple soil factors on plant community quantitative characteristics. This study approaches soil factors as driving forces to comprehensively examine their combined effects on desert plants, aiming to reveal the complex relationship between soil and desert plants in the Fukang desert-oasis ecotone. Specifically, we address: (1) Which soil driving factors significantly affect desert plant quantitative characteristics and what is their relative importance? (2) How do different soil layers differ in their factor composition, and which optimal soil layer should be selected for subsequent analysis? (3) How can redundancy analysis in constrained ordination quantitatively analyze relationships between individual soil driving factors and desert plant community quantitative characteristics?

1. Study Area Overview

The study area is located in the Fukang desert-oasis ecotone, southern Gurban Tunggut Desert, Xinjiang. Annual precipitation generally does not exceed 150 mm, with 70-100 mm concentrated in winter and spring. The maximum air temperature reaches 6-10°C, with annual accumulated temperature of 3000-5000°C. Relative humidity is 50-60%, while May-August humidity typically falls below 30%. Desert hinterland precipitation is only 50 mm, yet annual evaporation exceeds 2000 mm. Desert plants exhibit unique spatiotemporal distribution patterns across different growth environments, playing vital roles in restoring land productivity and preventing desertification in the ecotone.

Soil types are primarily gray-brown desert soil and aeolian sandy soil with light texture, low nutrient content, and low water-holding capacity. Dominant species include *Bassia dasyphylla*, *Suaeda glauca*, *Anabasis aphylla*, *Bassia sedoides*, *Tamarix ramosissima*, *Kalidium foliatum*, *Reaumuria songarica*, *Petrosimonia sibirica*, and *Haloxylon ammodendron*. Vegetation is monotonous with simple community structure, dominated by low dwarf shrubs with xerophytic characteristics.

2. Field Sampling and Methods

2.1 Field Sampling

Three north-south vertical transects were established in the Fukang desert-oasis ecotone, spaced 2 km apart. Each transect contained 50 plots (10 m × 10 m) with continuous sampling at 500 m intervals. Sampling was conducted during the peak biomass period (May-June). For each plot, plant species number, coverage, and abundance were recorded. Shrubs and all herbaceous plants were harvested using the harvest method. Fresh weight was measured with an electronic balance (precision 0.0001 g), then samples were oven-dried at 105°C for 24-48 hours to determine dry weight.

Soil samples were collected simultaneously using a five-point method at depths of 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm, and 30-50 cm. Samples from each layer were mixed and brought to the laboratory for analysis.

2.2 Experimental Methods

Soil moisture content was determined using the oven-drying method. Total salt content was calculated by summing ion concentrations. pH was measured potentiometrically. Total N was determined by the Kjeldahl method, total P by molybdenum-antimony anti-spectrophotometry, total K by flame photometry, and organic matter by potassium dichromate volumetric method.

2.3 Data Processing

Statistical analysis was performed using SPSS 19.0 to calculate means and standard deviations. Origin 8.0 was used for plotting variation in explanatory power of soil factors across different layers. CANOCO 5.0 software was employed for redundancy analysis (RDA) of relationships between desert plant quantitative characteristics and soil factors.

Prior to RDA, detrended correspondence analysis (DCA) was conducted. The gradient length of the first ordination axis was 0.636, indicating a linear relationship between desert plant quantitative characteristics and soil factors, thus making RDA appropriate. Monte Carlo permutation tests were used to assess significance, and variance inflation factors (VIF) were calculated to evaluate multicollinearity among the seven soil factors.

3. Results

3.1 Statistical Analysis of Plant Characteristics and Soil Factors

Desert plant fresh weight averaged 592.94 g/m^2 (range: 17.07-3658.00 g/m^2), while dry weight averaged 206.35 g/m^2 (range: 15.41-832.00 g/m^2). The difference between fresh and dry weight estimates plant water content. Coverage averaged 23.18% and abundance 32.83. Soil analysis revealed alkaline conditions (pH 8.25) with high salinization (total salt 2.90 g/kg) and low moisture

(9.54 g/kg). Organic matter averaged 10.16 g/kg (range: 2.51-11.52 g/kg), while total N, P, and K averaged 0.61, 0.90, and 20.36 g/kg respectively.

Coefficient of variation (CV) values for both plant quantitative characteristics and soil factors were below 100%, indicating weak spatial heterogeneity among different plots and meeting prerequisites for data analysis .

3.2 Variation in Explanatory Power Across Soil Layers

Analysis of explanatory power variation across soil layers showed soil moisture accounted for the highest proportion among soil factors in the 0-50 cm profile, reaching maximum values in the 0-20 cm layer (58.1%) and 20-30 cm layer. Other soil factors showed similar trends, with organic matter and total P reaching maxima in the 0-10 cm and 0-20 cm layers respectively. Total N showed an opposite increasing trend with depth, with its limiting effect on desert plants becoming more pronounced in deeper layers.

The explanatory power of soil factors for desert plant quantitative characteristics showed an initial brief increase followed by continuous decline with increasing depth. Below 30 cm, soil moisture increased slightly while other factors decreased continuously. Comprehensive analysis of factor explanatory power and variation curves revealed that relationships between soil factors and quantitative characteristics were strongest in the 0-20 cm layer [Figure 1: see original paper].

3.3 Redundancy Analysis of Driving Factors

RDA of four soil factors (selected after VIF screening) and desert plant quantitative characteristics showed that the first two axes explained 61.13% and 6.18% of variance respectively, with cumulative explanatory power reaching 67.31%. The correlation between quantitative characteristics and environmental factors was 0.9529 for Axis I and 0.4684 for Axis II, indicating that the first two axes effectively captured variation in desert plant quantitative characteristics and their relationships with soil factors, accounting for 98.71% of the species-environment relationship .

Correlation coefficients between soil factors and ordination axes revealed that soil moisture showed the highest correlation with Axis I (0.9309), establishing it as the key driving force. Total N showed the highest negative correlation with Axis I (-0.8938), representing a negative driving force. Organic matter showed the highest correlation with Axis II (0.9008), while total P showed weaker effects .

The two-dimensional ordination diagram illustrated relationships between plant quantitative characteristics (solid arrows) and soil factors (hollow arrows). Arrow length indicates correlation strength, while angle with ordination axes indicates correlation direction. Soil moisture and organic matter showed the longest arrows, confirming their importance as driving forces. Soil moisture correlated most strongly with abundance, while organic matter correlated most strongly with dry weight. Four factors showed positive correlations with quantitative characteristics, while total N was negatively correlated. Total P correlated positively with both fresh and dry weight but showed no relationship with coverage [Figure 2: see original paper].

Monte Carlo permutation tests revealed significant effects ($P < 0.01$) for soil moisture, organic matter, total N, and total P, which accounted for 58.1%, 52.9%, 52.4%, and 42.6% of explained variance respectively. The importance ranking of these driving factors was: soil moisture > organic matter > total N > total P .

3.4 Individual Factor Effects

t-value biplots analyzing individual soil factor effects showed that if a quantitative characteristic arrow fell completely within the solid circle, it indicated significant positive correlation with that soil factor; if within the dashed circle, significant negative correlation.

Soil moisture showed the strongest relationship with fresh weight, and was also significantly correlated with other characteristics. Organic matter was the primary driver affecting dry weight variation, showing positive correlations with abundance and coverage but not with fresh weight. Total N was negatively correlated with quantitative characteristics, showing significant negative correlation with fresh weight and acting as an inhibitory factor. Total P showed positive correlation with plant dry weight but no correlation with other characteristics. These results demonstrate that different quantitative characteristics respond differently to soil factors, but soil moisture and total N significantly affect overall desert plant performance.

4. Discussion

4.1 Soil Moisture as the Key Driving Force

Desert plant coverage in the ecotone is relatively low, closely related to special hydrological and soil conditions. Soil moisture is the key driving force affecting desert plant quantitative characteristics. Natural soil water replenishment primarily comes from winter snowmelt and spring precipitation, which exhibit strong spatiotemporal heterogeneity and randomness, causing spatial variation in desert plant community distribution.

Our finding of positive correlation between soil moisture and desert plant coverage aligns with Zhu Ruiqing et al.' s research showing significant negative correlation between water consumption and coverage. The RDA results reveal significant positive correlation between soil moisture and plant coverage and fresh weight, confirming soil moisture as the primary driving force for desert plant community quantitative characteristics. This is consistent with Li Qiaomei et al.' s findings on ephemeral plants in the Gurban Tunggut Desert, where surface soil water (0-20 cm) plays a crucial ecological role in community quantitative characteristics.

4.2 Effects of Soil Organic Matter

Soil organic matter primarily affects the 0-20 cm layer, showing positive correlation with desert plant dry weight and coverage. The ecotone's herbaceous plants are mainly ephemeral or pseudo-ephemeral species growing in spring when biological activity is intense, promoting litter decomposition and increasing dry weight. Although the mean organic matter content (10.16 g/kg) is below the national average (32.3 g/kg), it is higher than in pure desert soils (0.8-2.5 g/kg), likely due to the transition zone receiving more organic matter from herbaceous litter.

Research by Feng Lei et al. showed organic matter decreasing from northwest to southeast and from desert margins to hinterland. Our study area, located at the southern margin, shows higher organic matter due to significant human activity and dune fixation. Under adequate moisture, carbonate calcium facilitates decomposition of plant residues to form organic matter, providing sufficient nutrients for desert plant growth. This supports our finding of positive correlation between organic matter and plant biomass.

4.3 Total Nitrogen as a Negative Driving Force

Total soil nitrogen is a major limiting factor for desert plant growth. In the ecotone, total N content increases during rainfall periods, but spring precipitation is scarce, limiting organic matter formation and nitrogen accumulation. As a key organic component, insufficient total N inhibits nutrient absorption by desert plants.

Our results showing negative correlation between total N and plant community quantitative characteristics align with Thorup-Kristensen et al., who reported decreased soil biological activity with increasing nitrogen in desert ecosystems under fertilization. The negative correlation between total N and plant fresh/dry weight may result from plants increasing soluble protein content (stored as nitrogen) to enhance cell sap concentration and resist drought, ultimately reducing biomass compared to other regions.

4.4 Effects of Total Phosphorus

Soil pH affects phosphorus availability, with increasing pH enhancing phosphorus utilization by organisms. The study area's weakly alkaline soil (pH 8.25) had total phosphorus averaging 0.90 g/kg, significantly higher than mobile dunes and consistent with Xi Junqiang et al.' s findings of increasing total P with dune fixation.

Total P participates in oxidation-nitrification reactions, promoting phosphorus absorption by desert plants, especially synergistically with increasing soil moisture and organic matter. However, desert herbaceous plants under long-term drought may have different phosphorus demand mechanisms than mesic herbs. Despite low organic matter, positive correlation between total P and plant biomass indicates effective phosphorus absorption, possibly through root exudates (e.g., citric acid) releasing phosphorus from iron phosphate in low-phosphorus soils. The absorption mechanism warrants further investigation.

5. Conclusions

Analysis of soil driving forces on desert plants yielded the following conclusions:

1. Soil moisture, organic matter, total N, and total P are important soil driving forces for desert plant community quantitative characteristics, ranked by importance as: soil moisture > organic matter > total N > total P.

2. Soil moisture shows significant positive correlation with fresh weight, serving as the primary positive driving force for desert plant growth. Total N is negatively correlated with quantitative characteristics, acting as an inhibitory factor. Organic matter and total P are positively correlated with dry weight, while all four factors show positive correlation with coverage and abundance.

3. Environmental explanatory power of soil factors varies across soil layers, with the strongest correlation between surface soil (0-20 cm) factors and desert plant community quantitative characteristics. The relationship shows an initial increase then decrease with depth, consistent with cumulative environmental explanatory power trends.

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