Effects of Different-Aged Abandoned Cropland on Soil Moisture and Species Diversity in the Minqin Qingtu Lake Area (Postprint)

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Date: 2022-03-28T17:02:06+00:00

Abstract

Using a space-for-time substitution approach, we investigated and analyzed soil moisture dynamics and vegetation succession characteristics across abandoned croplands of varying abandonment ages (1, 2, 4, 8, 13, 20, 30, 40 years and CK) in the Qingtu Lake area of Minqin. The results indicated that: (1) With increasing abandonment duration, soil water content exhibited an overall pattern of initial decline, subsequent increase, and eventual stabilization. (2) With increasing abandonment duration, individual number, species number (S), and Margalef richness index displayed a fluctuating decreasing trend; Shannon diversity index and Pielou evenness index showed a pattern of initial increase followed by decrease and eventual stabilization; Simpson dominance index exhibited relatively minor overall variation and ultimately stabilized. (3) With increasing abandonment duration, the plant community underwent successional transition from Kochia scoparia → Halogeton glomeratus → Setaria viridis → Peganum nigellastrum → Suaeda microphylla → Lycium ruthenicum → Reaumuria songarica → Kalidium foliatum. (4) Simpson dominance index was highly significantly negatively correlated with soil water content in the 0–20 cm layer, while Shannon diversity index was highly significantly positively correlated with soil water content in the 0–20 cm layer, but showed no significant correlation with soil water content in the 20–40 cm layer; correlations between species number (S), Margalef richness index, Pielou evenness index and soil water content were not significant. It is evident that natural vegetation succession in arid regions is dependent on soil water content in the 0–20 cm layer.

Full Text

Effects of Different Years of Returning Farmland on Soil Moisture and Species Diversity in the Minqin Qingtu Lake Area

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Abstract

Using the space-for-time substitution method, we investigated soil moisture dynamics and vegetation succession characteristics in abandoned farmlands of different ages (1, 2, 4, 8, 13, 20, 30, 40 years, and control) in the Qingtu Lake area of Minqin. Results showed that: (1) Soil water content initially decreased, then increased, and gradually stabilized with increasing abandonment duration. (2) The number of individuals, number of taxa, and Margalef richness index showed fluctuating declining trends; Shannon diversity index and Pielou evenness index first increased then decreased before stabilizing; Simpson dominance index showed minor changes before reaching stability. (3) Plant communities underwent successional changes from *Kochia scoparia* to *Kalidium foliatum*. (4) Simpson dominance index was significantly negatively correlated with soil moisture in the 0–20 cm layer, while Shannon diversity index was significantly positively correlated with soil moisture in the 0–20 cm layer; no significant correlations were found with soil moisture in the 20–40 cm layer. No significant correlations were observed between taxa number, Margalef richness index, Pielou evenness index, and soil moisture. These findings indicate that natural vegetation succession in arid regions depends on soil moisture content in the 0–20 cm layer.

Keywords: Qingtu Lake; abandoned farmland; natural vegetation succession; soil moisture content; correlation

Introduction

Endorheic lakes are widely distributed throughout inland river basins in arid regions, playing crucial roles in ecosystem function. Numerous studies on plant diversity in various ecosystems—including forests, plateaus, grasslands, and meadows—have identified both natural factors (soil, topography, climate) and anthropogenic factors (returning farmland to forest) as key influences on plant diversity. Vegetation and soil represent interacting and mutually influential systems, with soil moisture distribution patterns resulting from combined soil and vegetation processes. However, research findings on the relationship between soil moisture and vegetation community characteristics remain inconsistent, pri-

marily due to differences in natural geography and environmental conditions across study areas.

Qingtu Lake, located at the downstream terminus of the Shiyang River basin, represents a critical case. Historically covering approximately 400 km^2, this terminal lake serves as an important barrier preventing the convergence of the Tengger and Badain Jaran deserts. However, ecosystem fragility, sparse vegetation, and extensive groundwater exploitation have intensified salinization and desertification in the Qingtu Lake area. Particularly since the 1950s, reduced upstream water flow combined with construction of the Hongyashan Reservoir in the Shiyang River' s middle reaches caused rapid lake drying and accelerated desertification in the downstream Minqin Oasis. Excessive groundwater exploitation further exacerbated environmental problems including declining water tables, land desertification, and vegetation degradation. Additionally, local policies of well closure and land reduction have resulted in large-scale farmland abandonment, severely damaging the Minqin Oasis ecosystem. Consequently, fundamental research on abandoned farmland and its rational protection has become critically important.

While previous studies on abandoned farmland in the lower Shiyang River have focused on soil, water, and vegetation aspects, research specifically examining correlations between soil moisture and vegetation in different-aged abandoned lands in the Qingtu Lake area remains limited. Using the space-for-time substitution approach, this study analyzes vegetation natural succession characteristics, soil moisture dynamics, and their interrelationships in abandoned farmlands of varying ages in the lower Shiyang River' s Qingtu Lake area. The objectives are to provide scientific theoretical foundations for ecosystem restoration in this region and technical support for ecological construction in Minqin and similar areas.

Materials and Methods

1.1 Study Area Overview

The study area is located in Xiqu Town, Minqin County, Gansu Province, China, with geographical coordinates of 39°01 44.11 -39°03 57.53 N, 103°35 9.84 - 103°37 55.49 E, and an average elevation of 1305 m. The region experiences a typical temperate continental arid climate, with an average annual temperature of 7.4°C, extreme minimum temperature of -28.8°C, and extreme maximum temperature of 38.1°C. Annual total radiation reaches 6000 $MJ \cdot m^{-2}$, with 2832.1 h of sunshine and average annual wind speed of 2.3 $m \cdot s^{-1}$. Annual precipitation is approximately 110 mm, concentrated in July–September and accounting for 70% of total rainfall. The area experiences 26.8 dust storm days annually, with a frost-free period of 175 days. Characterized by abundant light, strong evaporation, large diurnal temperature variations, scarce rainfall, and arid climate, the region' s soils are primarily gray-brown desert soils with high salinization. Landforms consist mainly of aeolian sand, low mountain,

and plain types. Dominant shrub species include *Reaumuria songarica*, *Lycium ruthenicum*, *Nitraria tangutorum*, *Kalidium foliatum*, and *Nitraria sibirica*, while herbaceous plants are primarily *Peganum nigellastrum*, *Salsola ikonnikovii*, *Suaeda glauca*, *Convolvulus arvensis*, *Halogeton arachnoideus*, *Chenopodium album*, and *Chloris virgata*.

1.2 Sample Plot Establishment and Vegetation Survey

In July 2019, we consulted with Minqin County forestry departments and local residents to accurately determine abandonment times of experimental plots. Secondary grassland vegetation in the area recovers naturally through natural succession. Plot elevations were relatively consistent, and different plots were located close enough to exclude effects of altitude and latitude on vegetation growth. Plots were unaffected by natural or anthropogenic disturbances. Under the condition of 基本相同的基本母质, we selected abandoned farmlands of 1, 2, 4, 8, 13, 20, 30, and 40 years, with 未退耕土地 (CK) as the control. All plots had previously grown the same or similar crops with comparable fertilization and irrigation management.

We established 100 m × 100 m sample plots in each site, with five 10 m × 10 m quadrats set at each plot' s center and corners to measure shrub and semi-shrub community characteristics including individual numbers, height, vegetation coverage, and crown width. Within each shrub quadrat, we established five 1 m × 1 m herbaceous quadrats to measure annual and perennial herb community characteristics including individual numbers, height, and vegetation coverage. We recorded community types, elevations, geographic coordinates, and soil types for each quadrat.

1.3 Soil Sample Collection

Concurrent with vegetation surveys in July 2019, we collected soil samples using an "S" sampling pattern across different-aged abandoned plots, establishing five sampling points per plot. Soil samples were collected from 0–20 cm and 20–40 cm layers using soil augers. Five soil samples from the same plot and layer were mixed to form one composite sample, with three replicates per layer. Samples were sealed in plastic bags, transported to the laboratory, and soil moisture content was determined using the oven-drying method.

1.4 Measurement Methods

1.4.1 Soil Moisture Measurement Soil moisture content was measured using the oven-drying method, expressed as weight percentage calculated as:

$$\text{Soil moisture content} = \frac{\text{Weight of water}}{\text{Weight of oven-dried soil}} \times 100\%$$

1.4.2 Species Diversity Measurement We calculated species diversity using Margalef richness index, Shannon diversity index, Pielou evenness index,

Simpson dominance index, and importance values. Formulas were as follows:

Important Value:

Important Value = (Relative Height+Relative Coverage+Relative Frequency)×100%

Simpson Dominance Index:

$$D = \sum_{i=1}^{S} \frac{N_i(N_i - 1)}{N(N-1)}$$

Shannon Diversity Index:

$$H' = -\sum_{i=1}^{S} P_i \ln P_i$$

Pielou Evenness Index:

$$E = \frac{H'}{\ln S}$$

Margalef Richness Index:

$$D_{\mathrm{MG}} = \frac{S-1}{\ln N}$$

Where P_i is relative frequency, N_i is the number of individuals in the ith taxon, S is the number of taxa, and N is the total number of individuals across all taxa.

1.5 Data Processing and Analysis

Experimental data were organized using Excel 2013. One-way ANOVA was performed using SPSS 20.0 for vegetation and soil data, with multiple comparisons conducted using Duncan' s method.

Results

2.1 Soil Moisture Variation Characteristics in Different-Aged Abandoned Farmlands

Figure 1 shows soil moisture content trends across different abandonment years and soil layers. With increasing abandonment duration, soil moisture content initially decreased, then increased, and gradually stabilized. Soil moisture in the 0–20 cm layer at 8–20 years of abandonment was significantly higher than other periods, reaching 9.41%, and showed significant differences from other abandonment stages. In the 20–40 cm layer, soil moisture peaked at 10.26% during 8–20 years, also showing significant differences. Soil moisture reached its minimum at 4 years of abandonment, with 4.43% in the 0–20 cm layer and 4.41% in the 20–40 cm layer, both significantly different from other stages.

2.2 Plant Community Species Composition and Important Values in Different-Aged Abandoned Farmlands

Table 2 shows life-form composition characteristics. A total of 42 plant species were recorded across the successional chronosequence, including 15 annual herbs (35.71% of total species), 16 perennial herbs (38.10%), and 1 each of woody deciduous liana and twining herbaceous liana (2.38% each). The remaining 9 shrub species accounted for 21.43% of total species.

Table 3 presents species composition and important values. The 42 species belonged to 16 families, with Chenopodiaceae (9 species), Amaranthaceae (8 species), and Solanaceae (5 species) comprising 78.57% of total species, indicating these families play important roles in vegetation succession. Species composition showed a pattern of "many species in few families, few species in many families," with most species being monotypic. Vegetation succession exhibited continuity, with *Halogeton arachnoideus* appearing continuously across different abandonment years, and progressive characteristics.

During early abandonment (1–4 years), communities were dominated by annual and perennial herbs such as *Convolvulus arvensis*, *Chenopodium album*, and *Kochia scoparia*, with few shrubs like *Kalidium foliatum* and *Tamarix chinensis*. After 4 years of abandonment, important values of annual herbs including *Halogeton arachnoideus*, *Kochia scoparia*, and *Setaria viridis* decreased significantly. After 8 years, annual and perennial herb species decreased markedly, with important values of *Suaeda glauca* and *Convolvulus arvensis* declining to 8–20%. Woody plants emerged for the first time, with annual herbs like *Chenopodium album*, *Kochia scoparia*, and *Lepidium apetalum* disappearing completely. Community dominants shifted from herbs to shrubs, with *Lycium ruthenicum* and *Kalidium foliatum* becoming dominant species. After 20 years, plant species richness decreased, with communities dominated by *Lycium ruthenicum* and *Kalidium foliatum* shrubs, indicating relatively stable community structure.

2.3 Species Diversity Changes in Different-Aged Abandoned Farmlands

Table 4 shows changes in individual numbers, taxa numbers, and diversity indices during 1–40 years of succession. With increasing abandonment duration, individual numbers gradually decreased. Taxa numbers and Margalef richness index showed fluctuating declines, increasing during 1–4 years to a maximum of 3.42, then decreasing. Shannon diversity index increased during 1–4 years, then gradually decreased, stabilizing after 13 years. Pielou evenness index increased during 1–4 years, reaching maximum values at 4–13 years, then gradually decreased and stabilized. Simpson dominance index peaked at 4–13 years but showed minor overall variation, eventually stabilizing. These patterns indicate that plant numbers decreased while community composition simplified with abandonment age.

2.4 Correlation Analysis Between Species Diversity and Soil Moisture

Table 5 presents correlation analysis results. Simpson dominance index showed highly significant negative correlations with soil moisture in both 0–20 cm and 20–40 cm layers. Shannon diversity index showed highly significant positive correlation with 0–20 cm soil moisture, but no significant correlation with 20–40 cm soil moisture. Taxa number (S) and Margalef richness index showed highly significant positive correlations with soil moisture in both layers. Pielou evenness index showed no significant correlation with soil moisture. These results demonstrate that soil moisture in the 0–20 cm layer significantly influences vegetation diversity in the Qingtu Lake area.

Discussion

3.1 Effects of Different Abandonment Years on Soil Moisture

The lower Shiyang River' s Qingtu Lake area belongs to the temperate continental arid climate zone, where soil moisture is essential for plant growth and a limiting factor for vegetation development in arid regions. During early abandonment, soils retained substantial moisture from previous cultivation, supporting numerous weeds dominated by annual and perennial herbs. Herbaceous growth consumed large amounts of soil moisture, while post-abandonment precipitation alone could not replenish water losses, causing gradual soil moisture decline. At 8–20 years of abandonment, communities were dominated by *Lycium ruthenicum* monocultures with reduced plant numbers and species, decreasing soil moisture consumption and allowing gradual moisture recovery. Subsequently, as communities stabilized, soil moisture recovered and stabilized. Overall, soil moisture showed a pattern of initial decline followed by increase and eventual stabilization. This pattern aligns with Chai et al.' s research on soil moisture and nutrient changes in different-aged abandoned lands in Qingtu Lake, but differs from Zou et al.' s findings in the Weibei dry plateau, likely due to differences in natural and environmental conditions, particularly the arid climate and precipitation patterns of the study area.

3.2 Effects of Different Abandonment Years on Species Diversity

During 1–40 years of community succession, increasing abandonment age led to decreasing individual numbers, while Margalef richness index and taxa numbers showed fluctuating declines, decreasing more slowly after 4 years, indicating gradual species simplification. Pielou evenness index increased during 1–4 years, then gradually decreased and stabilized after 13 years. Shannon diversity index increased initially, then gradually decreased and stabilized. Simpson dominance index peaked at 4–13 years but showed minor overall variation before stabilizing. These patterns align with Li et al.'s research on vegetation succession in salinized abandoned lands in the lower Shiyang River, but differ from Bai et al.' s research in the Loess Plateau hilly-gully region and Li et al.' s study in typical steppe abandoned lands, likely due to differences in hydrology, soil, topography, and

climate. This demonstrates that plant communities gradually develop toward simplified, stable states during natural succession.

3.3 Factors Influencing Species Diversity in Abandoned Farmlands

Vegetation and soil moisture share complex, close ecological relationships. Plant growth consumes soil moisture, leading to continuous water decline. Our correlation analysis revealed that Simpson dominance index was significantly negatively correlated with Shannon diversity index and Pielou evenness index, while taxa number (S) and Margalef richness index showed highly significant positive correlations with soil moisture in both layers. Shannon diversity index was highly significantly positively correlated with 0–20 cm soil moisture, while Simpson dominance index was highly significantly negatively correlated with 0–20 cm soil moisture. No significant correlations were found between Pielou evenness index and soil moisture, suggesting other factors limit plant growth. Research indicates that vegetation adapted to long-term environmental conditions develops characteristic attributes, with relatively uniform interspecies distribution and consequently weak response to moisture changes. In this study, vegetation grew under arid, water-deficient conditions, and as succession progressed, plants adapted to habitat conditions, resulting in no significant correlation between species evenness and soil moisture.

While this study focused on moisture dynamics, species diversity changes, and their correlations, previous research indicates that species diversity relates not only to soil moisture but also to soil nutrients and carbon-nitrogen cycling. Future research should strengthen investigations into relationships between species diversity and these additional factors.

Conclusions

1) During natural recovery of abandoned farmlands in the Minqin Qingtu Lake area, soil moisture content initially decreased, then increased, and gradually stabilized with increasing abandonment duration, with no significant differences between soil layers.

2) A total of 42 plant species were recorded in the study plots, showing a pattern of "many species in few families, few species in many families." Vegetation succession exhibited continuity and progressive characteristics, with plant communities gradually developing toward simplified, stable states.

3) Vegetation and soil moisture are closely correlated. Simpson dominance index showed highly significant negative correlations with Shannon diversity index and Pielou evenness index, while taxa number (S) and Margalef richness index showed highly significant positive correlations with soil moisture. Shannon diversity index was highly significantly positively correlated with 0–20 cm soil moisture, while Simpson dominance index was highly significantly negatively correlated with 0–20 cm soil moisture.

Soil moisture in the 0–20 cm layer plays a critical role in natural vegetation succession.

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