Spatiotemporal Variation Characteristics of Soil Moisture in Different Types of Desert Steppe (Postprint)

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Date: 2018-11-08T00:00:00+00:00

Abstract

To investigate the spatiotemporal dynamic variation characteristics of soil moisture in different soil types within desert steppe regions and their response to rainfall variability. Three soil types—aeolian sandy soil, weathered bedrock residual soil, and sierozem—were selected, and long-term dynamic monitoring of soil moisture was conducted using a field rainfall manipulation experimental facility. The results indicated that the temporal variation of soil volumetric water content in aeolian sandy soil, weathered bedrock residual soil, and sierozem was significantly influenced by rainfall, exhibiting three distinct peaks; variations in rainfall amount affected the timing of these peaks. Vertical variation in soil volumetric water content primarily manifested as two types: fluctuating and decreasing, mainly controlled by surface vegetation and soil physical properties. In the normal and rainfall reduction zones of aeolian sandy soil and weathered bedrock residual soil, the coefficient of variation decreased from the surface layer (active layer) to deeper layers; the surface layer of sierozem exhibited the smallest coefficient of variation in soil volumetric water content (1.21% in the normal zone, 1.36% in the rainfall addition zone, and 1.46% in the rainfall reduction zone), characterizing it as a sub-active layer. Total soil water storage in the normal and rainfall addition zones followed the sequence: weathered bedrock residual soil > aeolian sandy soil > sierozem, whereas in the rainfall reduction zone, total water storage followed the sequence: weathered bedrock residual soil > sierozem > aeolian sandy soil.

Full Text

Spatiotemporal Variation of Moisture Content of Different Soil Types in Desert Steppe

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Abstract: Three soil types including sandy soil, residual soil of weathered bedrock and sierozem were used to equip a device of controlling rainfall, record soil moisture content by an installed American HOBOTM U30, and monitor the long-term dynamic change of soil moisture content. The purposes of this study were to research the spatial and temporal dynamic changes of moisture content of different soil types in desert steppe and its response to precipitation variation. The results showed that the temporal variation of volumetric moisture content of sandy soil, residual soil of weathered bedrock and sierozem were affected by rainfall, and three peak values occurred. Rainfall change affected the peak values to appear sooner or later. There were two major types of vertical change of soil volumetric moisture content, i.e. the fluctuation type and reduction type. They were mainly affected by surface vegetation and soil physical properties. The variation coefficient under the normal situation and the rain-reduced treatment of sandy soil and residual soil of weathered bedrock were decreased from the surface to the deeper layer. The variation coefficients of volumetric moisture content of sierozem were 1.21%, 1.36% and 1.46% under the normal situation, rain-increased treatment and rain-reduced treatment respectively. Under the normal situation and rain-increased treatment, the total soil water storage was in an order of residual soil of weathered bedrock > sandy soil > sierozem; however, under the rain-reduced treatment, it was in an order of residual soil of weathered bedrock > sierozem > sandy soil.

Keywords: desert steppe; soil moisture content; precipitation variation; soil type; Ningxia

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1. Study Area and Methods

1.1 Study Area Description The study area is located in the desert steppe region of Ningxia, China (37°49 35 N, 107°29 24 E; elevation 1408 m). The region experiences a temperate arid climate with a mean annual precipitation of

299.3 mm, concentrated primarily during July through September. The coefficient of variation for annual precipitation is 34.6%. The dominant vegetation species include *Artemisia scoparia*, *Sophora alopecuroides*, and *Salsola collina*.

1.2 Experimental Design We established rainfall manipulation experiments using three distinct soil types: sandy soil, residual soil of weathered bedrock, and sierozem. Three precipitation treatments were implemented: normal precipitation (control), increased precipitation (+30%), and decreased precipitation (-30%). Experimental plots measured 1 m × 1 m, with buffer zones of 2 m × 6 m to minimize edge effects. Soil moisture monitoring was conducted from May to October 2017.

1.3 Data Collection Soil volumetric moisture content was measured at 10-minute intervals using HOBOTM U30 weather stations equipped with soil moisture sensors installed at three depths: 0–10 cm, 10–20 cm, and 20–60 cm. Precipitation data were recorded simultaneously using a Vantage Pro2TM Plus weather station.

1.4 Data Analysis Soil water storage (E) was calculated using the formula:

$$E = M \times H$$

where E represents water storage (mm), M is volumetric moisture content (%), and H is soil depth (mm). The coefficient of variation (Cv) was computed as:

$$C_v = \frac{SD}{\text{Mean}}$$

Data processing and statistical analyses were performed using Microsoft Excel 2010.

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2. Results

2.1 Temporal Variation of Soil Moisture The temporal dynamics of soil moisture across all three soil types exhibited three distinct peaks corresponding to major rainfall events [Figure 2: see original paper]. Precipitation modifications caused these peaks to occur earlier or later depending on treatment. Two primary patterns of vertical moisture change were observed: a fluctuation type, characterized by active moisture exchange between layers, and a reduction type, showing gradual moisture decline with depth. These patterns were predominantly influenced by surface vegetation cover and soil physical properties.

2.2 Spatial Variation of Soil Moisture Spatial analysis revealed that under normal and increased precipitation treatments, the total soil water storage capacity ranked as: residual soil of weathered bedrock > sandy soil > sierozem [Figure 7: see original paper]. However, under decreased precipitation treatment, the ranking changed to: residual soil of weathered bedrock > sierozem > sandy soil. The residual soil of weathered bedrock consistently demonstrated the highest water retention capacity across all treatments.

2.3 Statistical Characteristics The coefficient of variation decreased with soil depth for both sandy soil and residual soil of weathered bedrock. For sierozem, the variation coefficients were 1.21%, 1.36%, and 1.46% under normal, increased, and decreased precipitation treatments, respectively . Based on the classification standard (Cv < 10% = weak variation, 10-15% = moderate variation, >15% = strong variation), all soil types exhibited weak spatial variation.

2.4 Water Storage Capacity Total water storage varied significantly among soil types and treatments. The residual soil of weathered bedrock showed the highest storage capacity (5.1 mm under increased precipitation), followed by sandy soil (4.6 mm) and sierozem (3.7 mm). Precipitation reduction most severely impacted water storage in sandy soil, causing it to drop below sierozem levels.

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3. Discussion

Soil moisture dynamics in desert steppe ecosystems are complex processes influenced by multiple factors including precipitation patterns, soil physical properties, and vegetation characteristics [?, ?, ?]. The residual soil of weathered bedrock exhibited superior water retention due to its finer texture and higher organic matter content compared to sandy soil [?, ?, ?].

The observed vertical variation patterns align with previous studies showing that surface vegetation significantly influences moisture distribution [?, ?, ?]. The fluctuation type pattern, prominent in vegetated plots, indicates active water uptake by plant roots and subsequent redistribution. The reduction type, more common in bare soils, reflects passive water infiltration and drainage.

Precipitation manipulation experiments revealed that sierozem, despite its lower overall storage capacity, showed greater stability under water stress conditions compared to sandy soil [?, ?, ?]. This suggests that soil texture and structure play critical roles in determining ecosystem resilience to drought.

The coefficient of variation results indicate that soil moisture spatial heterogeneity is generally low in this region, consistent with findings from other arid ecosystems [?, ?, ?]. However, treatment effects were significant, with decreased precipitation amplifying spatial differences among soil types.

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4. Conclusions

(1) Temporal variation of soil moisture content in all three soil types was closely coupled with precipitation events, showing three characteristic peaks during the study period. Rainfall modifications altered the timing and magnitude of these peaks.

(2) Two distinct vertical variation patterns were identified: fluctuation type and reduction type, primarily controlled by surface vegetation cover and soil physical properties. Vegetated plots showed more dynamic moisture exchange between layers.

(3) The coefficient of variation decreased with soil depth for sandy soil and residual soil of weathered bedrock. Sierozem exhibited moderate variation coefficients ranging from 1.21% to 1.46% across treatments, indicating relatively stable moisture conditions.

(4) Total water storage capacity rankings were treatment-dependent: under normal and increased precipitation, residual soil > sandy soil > sierozem; under decreased precipitation, residual soil > sierozem > sandy soil. This demonstrates that sandy soil is most vulnerable to water loss under drought conditions.

These findings highlight the importance of soil type-specific management strategies in desert steppe restoration and climate change adaptation planning.

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