Postprint: Soil Available Water and Water Holding Capacity Under Different Vegetation Types in the Loess Hilly and Gully Region

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Date: 2018-06-09T00:00:00+00:00

Abstract

Taking different vegetation types in the Fangta Watershed of the Loess Hilly and Gully Region as the research object, and based on field investigations, the centrifuge method was employed to determine soil water content at different suction pressures in the 0-10 cm and 10-20 cm soil layers under various vegetation types, and the Van Genuchten model was utilized to fit the soil water characteristic curves. A comparative analysis was conducted on the soil water characteristic curves, soil water availability, and water-holding capacity across different soil layers and vegetation types. The results indicated that: with the progression of vegetation restoration, significant differences emerged in the soil water characteristic curves among different vegetation types, yet their slopes remained essentially constant, and all soil water characteristic curves for the 0-10 cm and 10-20 cm layers under different vegetation types exhibited an approximately S-shaped pattern. The ranges of soil available water in the 0-10 cm and 10-20 cm layers under different vegetation types were 22.65%-26.80% and 23.97%-28.13%, respectively, displaying a trend (except for Bothriochloa ischaemum communities and Robinia pseudoacacia forests) where perennial Artemisia-grass communities were lower than shrub communities but higher than annual herb communities. The soil water-holding capacity of different vegetation types showed no significant difference in the 0-10 cm layer, while in the 10-20 cm layer it demonstrated that perennial Artemisia-grass communities were lower than shrub communities but higher than annual herb communities, with Bothriochloa ischaemum communities being the highest and Robinia pseudoacacia forests being the lowest. Robinia pseudoacacia forests exhibited both low available water content and soil water-holding capacity; it is recommended to implement appropriate thinning and promote near-natural restoration to achieve sustainable utilization of soil water, and to avoid planting Robinia pseudoacacia in water-deficient sunny slope areas. This study holds significant importance for the sustainable utilization of soil water, vegetation restoration, and scientifically rational vegetation

configuration in the study region.

Full Text

Soil Water Availability and Holding Capacity of Different Vegetation Types in the Hilly-Gullied Region of the Loess Plateau

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DOI: 10.5846/stxb201705170914

Abstract

This study investigated different vegetation types in the Fangta watershed of the Loess Plateau' s hilly-gullied region. Based on field investigations, soil moisture at different suction levels in the 0-10 cm and 10-20 cm soil layers was measured using a high-speed centrifuge. The Van Genuchten model was employed to fit soil water characteristic curves, and parameters including soil water characteristic curves, soil water holding capacity, and soil water availability in the 0-10 cm and 10-20 cm layers were compared across vegetation types.

The results showed that as vegetation restoration progressed, soil water retention curves exhibited obvious differences among vegetation types, though their slopes remained essentially unchanged. All soil water retention curves among different vegetation types displayed approximate "S" shapes. The range of soil available water in the 0-10 cm and 10-20 cm layers was 22.65%-26.80% and 23.97%-28.13%, respectively. Soil moisture availability in grass communities and perennial communities was greater than that in annual herbaceous communities but less than that in shrub communities, except for the *Bothriochloa ischaemum* community and *Robinia pseudoacacia* forest.

In the 10-20 cm layer, soil water capacities of grass communities and perennial communities were higher than those of annual herbaceous communities and lower than those of shrub communities. The maximum capacity occurred in the *Bothriochloa ischaemum* community, while the minimum occurred in the *Robinia pseudoacacia* forest. As soil available water and soil water capacity of *Robinia pseudoacacia* were relatively low, intermediate cuttings can be implemented to promote natural recovery and eventually realize sustainable water utilization in artificial forests. *Robinia pseudoacacia* should be avoided in water-deficient areas such as sunny slopes. This research provides important insights for sustainable water utilization, vegetation restoration, and scientific vegetation configuration in the study area.

Keywords: hilly-gullied region of the Loess Plateau; vegetation types; soil water retention curve; soil available water; soil water holding capacity

Introduction

The Loess Plateau region suffers from severe soil erosion due to its geographical location, soil properties, and vegetation destruction from human activities. Water and gravity erosion are interwoven, creating a fragmented landscape with severely damaged natural vegetation and loose soil structure. This represents one of the most serious soil erosion areas in China and globally, and one of China's most severely degraded ecosystems. The Chinese government has implemented large-scale reforestation programs, leading to some vegetation recovery. However, increased transpiration and plant water consumption, combined with low rainfall, have made water a limiting factor for plant growth and ecosystem reconstruction in this region.

Understanding how soil water retention and availability vary among different restored vegetation types has become an urgent issue. Clarifying changes in soil water holding capacity and availability across vegetation types after years of reforestation is crucial for vegetation restoration and scientific vegetation configuration. Soil available water, which vegetation can effectively utilize, is vital for plant growth, while soil water holding capacity reflects soil drought resistance and water release capacity. Studying soil available water and holding capacity is essential in the arid and semi-arid Loess Plateau.

Previous research has investigated soil water holding capacity and availability. Studies have examined the effects of bulk density, water-retaining agents, fertilization, landforms, and organic compounds on soil water retention. Others have focused on forest land, post-fire Mediterranean shrubland, overgrazed grasslands, and eroded black soils. However, systematic analyses of soil water holding capacity and availability across vegetation succession stages—from annual herb communities to perennial Artemisia-grass communities to shrub communities and artificial forests—are scarce. This study selected different vegetation communities in the Fangta watershed of Ansai County, Shaanxi Province, to analyze soil water characteristic curves and properties, providing a basis for sustainable soil water utilization during vegetation restoration.

1. Study Area Description

The study area is located in the Fangta watershed of Ansai County, Yan' an City, Shaanxi Province, covering 8.67 km². The region has an average annual temperature of 8.7°C and average annual rainfall of 542.6 mm, concentrated in July-September with frequent heavy storms. The watershed has implemented large-scale reforestation programs, resulting in extensive artificial forest-shrub vegetation and naturally restored vegetation.

Natural vegetation succession generally progresses from annual herb communities to perennial Artemisia-grass communities, forming various plant communities dominated by species such as *Artemisia scoparia*, *Artemisia gmelinii*, *Stipa bungeana*, *Lespedeza davurica*, and *Bothriochloa ischaemum*. Shrubs are mainly artificial *Caragana intermedia* and naturally formed *Periploca sepium* and *Sophora viciifolia*. The dominant tree species is artificial *Robinia pseudoacacia*.

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2. Sample Plot Selection and Soil Sampling

In mid-September 2015, based on natural restored vegetation and artificial forest-shrub planting conditions in the study area, sample plots with similar slopes (21°–32°), flat surfaces without fish-scale pits, no severe erosion gullies, and close proximity were selected in the Fangta watershed. Different vegetation types and controls each had three replicate plots. Plot information was determined through multiple household interviews and field verification. Vegetation surveys were conducted in each plot using diagonal transects from top to bottom. provides basic information for the selected plots.

Soil samples were collected from the 0–10 cm and 10–20 cm layers in each plot using diagonal transects. Considering that surface soil physicochemical properties change more noticeably with vegetation restoration, undisturbed soil samples for bulk density and water characteristic curves were collected using rings (100 cm^3 volume). Samples for particle composition were air-dried after removing roots and small stones. Samples for organic matter were collected with soil augers.

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3. Laboratory Analysis

Soil particle composition was measured using an MS2000 laser particle size analyzer with the international classification system. Bulk density was determined using the ring method. Organic matter was measured by the external heating method. Soil water characteristic curves were determined using the centrifuge method with a suction range of 1–1000 kPa.

3.1 Soil Water Characteristic Curve Model

The relationship between soil matric potential (soil water suction) and soil water content is called the soil water characteristic curve, which reflects the relationship between soil water and energy and is a fundamental curve for soil water movement. Many empirical formulas have been proposed, including Brooks-Corey, Gardner, Campbell, and Van Genuchten models. The Van Genuchten model provides good fitting results for both coarse and fine-textured soils and was selected for this study.

The Van Genuchten model equation is:

 - / - = [1 + (h)]

where is soil water content, is residual water content, is saturated water content, n is the shape coefficient, is the reciprocal of air-entry value, and h is soil suction.

3.2 Soil Available Water Boundaries

To clearly display soil water characteristic curve features, curves were plotted with soil water content on the horizontal axis and pF values (logarithm of soil suction in cm water column) on the vertical axis. Based on previous research, pF = 1.8 corresponds to field capacity, pF = 3.8 to temporary wilting coefficient, and pF = 4.2 to permanent wilting coefficient. Available water was calculated as water content between pF 1.8–4.2, readily available water between pF 1.8–3.8, and slowly available water between pF 3.8–4.2.

3.3 Specific Water Capacity Calculation

Specific water capacity measures soil water availability to plants and reflects soil water holding performance. It represents the slope of the soil water characteristic curve—the change in soil water content per unit change in matric potential. The calculation formula is:

C = d /dh

where C is specific water capacity, is soil water content, and h is soil suction. Higher specific water capacity indicates greater soil water supply capacity, meaning more water is available to plants with less suction required.

3.4 Data Analysis

Statistical analysis was performed using Excel 2007, SPSS 20.0, and Sigmaplot 12.5. The least significant difference (LSD) method was used for significance testing of soil water parameters, soil properties, and specific water capacity.

4. Results

4.1 Soil Water Characteristic Curves of Different Vegetation Communities

Based on soil water characteristic curves, the 0–10 cm and 10–20 cm layer curves for different vegetation types are parallel curves. According to curve density, they can be divided into three suction segments: low suction ($pF < 1.7$), medium suction ($1.7 < pF < 2.01$), and high suction ($2.01 < pF < 4.01$). In the low suction segment, curves are relatively dispersed with some crossings, representing the transition from low to medium-high suction. In the high suction segment, curves are closely arranged parallel curves.

Soil water content decreases with increasing suction, with the decreasing trend gradually slowing. At the same water content, higher suction indicates stronger water holding capacity. *Caragana intermedia* forest shows the best water holding capacity, while *Stipa bungeana* community shows the poorest. [Figure 1: see original paper] illustrates soil water retention curves for different vegetation types.

The Van Genuchten model was used to fit curves for quantitative analysis. All vegetation types showed excellent fitting effects ($P < 0.01$), with fitted curves essentially overlapping measured curves. Saturated water content ( ) and shape coefficient (n) varied significantly with vegetation restoration, indicating differences in soil water characteristic curves among vegetation types in the low suction segment. Residual water content ( ) differences appear in the high suction segment, while (reciprocal of air-entry value) differences indicate varying pore size distributions during vegetation restoration.

4.2 Soil Properties of Different Vegetation Types

Analysis of soil properties across vegetation communities reveals that *Bothriochloa ischaemum* community has significantly higher clay content than other communities in both layers ($P < 0.05$). *Robinia pseudoacacia* and bare land have significantly higher sand content than other communities. Clay content increases while sand content decreases from annual herb communities to perennial Artemisia-grass communities to shrub communities, indicating improving soil water holding capacity with vegetation restoration.

Organic matter content varies significantly among communities. In the 0–10 cm layer, *Artemisia giraldii* community has significantly higher organic matter (13.21 g/kg) than others, while *Stipa bungeana*, *Artemisia scoparia*, *Robinia pseudoacacia*, and bare land have significantly lower content. In the 10–20 cm layer, *Artemisia giraldii* and *Bothriochloa ischaemum* communities have higher organic matter, while *Stipa bungeana*, *Artemisia scoparia*, *Robinia pseudoacacia*, and bare land have lower content. and present detailed soil properties for both layers.

Bulk density shows that *Bothriochloa ischaemum* community has higher values than other communities in both layers, while *Caragana intermedia* and *Sophora viciifolia* communities have lower values.

4.3 Soil Water Availability of Different Vegetation Communities

Soil water availability varies among vegetation types. In the 0–10 cm layer, available water content ranges from 22.65% to 26.80%, with *Bothriochloa ischaemum* community showing the maximum and *Stipa bungeana* community the minimum. *Bothriochloa ischaemum* community is significantly greater than *Robinia pseudoacacia* forest ($P < 0.05$). Readily available water shows the same trend, ranging from 0.35% to 0.91%.

In the 10-20 cm layer, available water ranges from 23.97% to 28.13%, with *Bothriochloa ischaemum* community significantly greater than bare land, *Artemisia scoparia* community, and *Artemisia gmelinii* community. The pattern generally shows perennial Artemisia-grass communities intermediate between shrub communities and annual herb communities. [Figure 3: see original paper] displays soil available water for different vegetation types.

4.4 Specific Water Capacity of Different Vegetation Communities

Specific water capacity quantity levels vary with suction. As suction increases to wilting coefficient levels, the order of magnitude decreases from 10 ^{1} to 10 ^{3} mL/kPa. At field capacity suction (pF = 1.8), specific water capacity ranges from 0.5-1 kPa ^{1}, allowing plants to absorb considerable water. At temporary and permanent wilting coefficients (pF = 3.8 and 4.2), specific water capacity drops to 5-10 kPa ^{1} and 1–5 kPa ^{1}, respectively, making water absorption difficult.

In the 0–10 cm layer, no significant differences exist among vegetation types at suctions below 20 kPa. Above 1554 kPa, significant differences emerge ($P < 0.05$), with *Bothriochloa ischaemum* community showing higher values. In the 10–20 cm layer, specific water capacity shows no significant differences across vegetation types.

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5. Discussion

Soil available water in both layers generally follows the trend: perennial Artemisia-grass communities < shrub communities > annual herb communities. Soil water holding capacity shows a similar pattern: perennial grass communities > annual herb communities < shrub communities. *Bothriochloa ischaemum* community has the highest water holding capacity, while *Robinia pseudoacacia* forest has the lowest.

Different plant communities, with their distinct dominant species, influence soil water availability and holding capacity through biological characteristics.

Shrub communities have larger canopy and aboveground biomass, producing more litter and dead roots for humus transformation, thereby increasing soil organic matter content and improving soil water availability and holding capacity. Their larger root biomass secretes more cementing substances, forming better soil structure, increasing porosity, reducing bulk density, and enhancing water availability.

Annual herb communities, being in the initial restoration stage, have lower biomass and nutrient accumulation capacity, with nutrient consumption exceeding accumulation, resulting in poorer soil structure and lower water availability. Perennial Artemisia-grass communities have more complex structure and biodiversity than annual herbs, accelerating organic matter decomposition, increasing organic matter content, gradually reducing bulk density, and significantly improving soil environment, leading to greater water holding capacity.

In soils with low organic matter content, soil texture significantly influences soil properties. *Bothriochloa ischaemum* community has higher clay content, increasing soil cohesion and resulting in higher water holding capacity and available water. *Robinia pseudoacacia* forest, with low organic matter content, shows smaller water holding capacity.

Soil water content differences appear not only among vegetation types but also between soil layers. The 0-10 cm layer generally has higher effective water content than the 10-20 cm layer. Long-term erosion processes have removed better-structured surface soil, leading to nutrient-poor conditions. Natural vegetation recovery in severely degraded ecosystems is difficult and time-consuming without proper intervention. In this study area, soil erosion continues during vegetation restoration, causing persistent surface soil loss and poor soil structure.

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6. Conclusion

With vegetation restoration, soil available water content and water holding capacity within the same soil layer generally follow the pattern: perennial Artemisia-grass communities > annual herb communities < shrub communities. *Bothriochloa ischaemum* community has higher soil available water content than other vegetation types in both the 0-10 cm and 10-20 cm layers. Under the same vegetation type, soil available water is higher in the 0-10 cm layer than in the 10-20 cm layer.

Robinia pseudoacacia forest has relatively low available water and water holding capacity in both layers. To achieve sustainable soil water utilization, intermediate cutting can be applied to promote natural recovery and succession, and large-scale planting of *Robinia pseudoacacia* should be avoided in water-deficient sunny slope areas. This research provides important guidance for sustainable water utilization, vegetation restoration, and scientific vegetation configuration in the study region.

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