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The response of soil moisture content to rainfall events in semi-arid area of Inner Mongolia

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Abstract

Based on the 2 months' data of soil moisture and typical meteorological data, using the water balance principle, the dynamics and distribution patterns of the soil moisture caused by rainfall were studied in Taipusi County, a semi-arid area in Inner Mongolia. The results show soil water storage and evapotranspiration differed greatly among different slope positions, gradually reduced from the upper slope position to the lower. The increase of soil water storage decreased from the upper slope positions to the lower when the rainfall occurred, and it was negatively related to initial soil water storage, Additionally, rainfall in the area produced excess-infiltration runoff which increased from the upper slope positions to the lower, areas without vegetation cover were the runoff output areas and areas with vegetation cover were the runoff input areas.

Keywords: Soil water storage ; Evapotranspiration ; Runoff ; Slope positions ; Semi-arid area

1. Introduction

In arid and semi-arid areas, water is the most active factor in environmental system. The impacts of topography, vegetation and soil on rainfall redistribution have been the hot issues for the studies on water use and ecological-environmental protection in semi-arid areas [1, 2, 3]. At present, a considerable amount of research which studies on spatial heterogeneity of the soil moisture and its influencing factors has made much progress. Apart from the nature of soil, rainfall characteristics [4], land use [5, 6], terrain [7, 8] and other environmental factors also affect the spatial variability of soil water. Moreover, since slope is the basic unit of landscapes, studying on the temporal and spatial variability of soil moisture according to different slope can provide a basis for understanding the characteristics of soil moisture in a larger scale [9].

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Rainfall is the main source of soil moisture. Because vegetation is highly dependent on water, water becomes a key factor that affects survival, growth of plants and supportive from environment to vegetation, which makes water have a huge limitation on steady growth and recovery of vegetation [10]. This article analyzes the dynamics and the distribution patterns of the soil moisture caused by rainfall to reveal the relationship between rainfall events and soil moisture in the semi-arid area. This will be of significance for large-scale empirical practices of vegetation-based ecological environment construction projects in semi-arid regions.

There are many methods to get the soil moisture data in the past such as the drying over heat method [11, 12] and time domain reflectometry method [13, 14]. However, most data got by these methods is instantaneous and it is hard to control the consistency of sampling time. Now the method using soil moisture sensor is rare to get soil moisture data on the plant community with full time positioning system and quantitative analysis of experimental data, so this paper attempts to make some preliminary contribution in these aspects.

2. Materials and methods

2. 1 Study sites

Our experiment field (42 ° 06.934 '-42 ° 07.100'N, 115 ° 27.743 '- 115 ° 27.978'E) is located in Taipusi County, Inner Mongolia. Experimental site is a rectangle with a total area of 20000m^2 (400m × 50m) protected by fence around. It has a semi-arid continental climate with the average temperature is -18℃ and minimum temperature is -36℃. Annual frost-free period is about 100 days. The vegetation is dominated by Stipa krylovii steppe and Leymus chinensis steppe. Caragana microphylla shrubbery **i**s widely distributing. The slope ranges from 2.5° to 7.5°. Soil at the site is chestnut soil with low organic matter content [15].

2.2 Data presentation

The experiment field was established in November 2007. The Dynamet automatic weather station installed in the center of the field recorded the wind speed, temperature, rainfall and total radiation. ECH_2O soil moisture monitoring system produced by Licor Corporation was used to measure the whole period and fixed-point data on a typical semi-arid of Taipusi hillslope, the sensor was calibrated by engineers after installation. Six sampling sites were selected for the study by taking every two of them as a group for observation points distributed on the upper slope, middle slope and lower slope respectively. Sample points with and without vegetation were interval distributed. We determined if samples were with or without vegetation cover by the coverage of vegetation upon the soil moisture sensor. If there were less than 5% of vegetation covering on the sample points, we considered it as samples without vegetation; otherwise we defined them as the samples with vegetation. Soil in the vertical direction of samples was loose, and soil bulk density of 0-30cm was between 1.28 and 1.53. At the same slope, the bulk density without vegetation on the samples was higher than that with the vegetation. The unit of soil moisture measurement system is the volume percentage (VWC), accuracy ± 3%. The depths of soil layer in soil moisture sensor measurement were 0-15cm, 15-30 cm, 30-45 cm, 45-60cm and 60-75cm.

We selected two months of monitoring data from July to August, 2009. The count frequency of moisture sensor was once per hour. This paper took the mean of 24 records of daily data as the soil moisture on that day, then multiplied the mean value by depth of soil layer thickness(150mm) to get the soil water storage (unit is mm).

Occurrence of rainfall will cause sharp increase in soil water storage. Data from 7-17 to 7-19 (Fig. 1) were selected to analyze the response of slope soil moisture to the rainfall, particularly to the typical strong rainfall. Data from 7-26 to 8-24 were selected to quantitatively describe the evapotranspiration in different slope positions because of rare rainfall in this period.

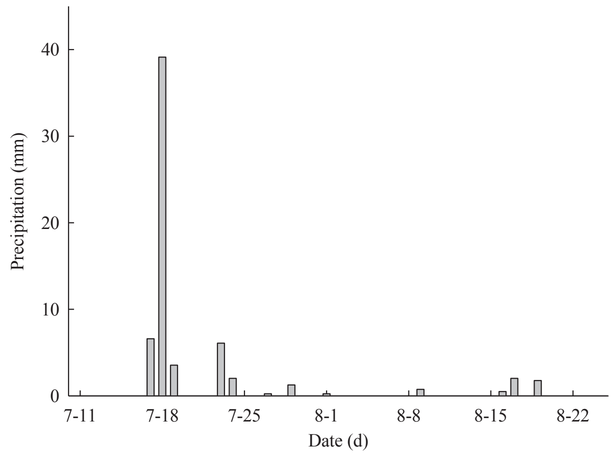

Fig.1 The precipitation of the slope

2.3 Methods

Lv et al. suggested that considering the soil water balance in the general precipitation in arid or semi-arid region [16], it's unnecessary to take deep water leakage into account. According to water balance theory, we considered the sample as a cylinder without exchange of water with its surrounding. During a certain time, water balance equation was composed of five steps: precipitation (P), canopy interception (I), transpiration (Ev), surface runoff (R) and soil water storage changes ($\Delta\theta$), and precipitation would be assigned to the other four segments.

$$P = I + Ev + R + \Delta\theta$$

Based on the actual situation, canopy interception（I）in the formula can be approximated to 0. Because of sporadic rainfall, it did not produce runoff from 7-26 to 8-24 (R = 0), then the total evapotranspiration: $Ev = \Delta\theta - P$. We can use evapotranspiration divided by the total number of days to get evapotranspiration of the slopes.

3. Results

3.1 Soil moisture characteristics

The active layer was mainly in the 0-30cm (Fig. 2). When heavy rainfall occurred, on either samples without vegetation cover or samples with vegetation cover, the soil moisture in the surface of 0-30cm will respond rapidly. However, there was more water infiltration in the samples with vegetation cover than that without vegetation cover. Below 30cm of the soil in the middle and lower slope, there was more soil water storage in the samples without vegetation cover. Soil water storage had individual changes in 30-60cm layer of samples, which was the transition layer. The soil water storage of samples in the 60-75cm remained constant and belonged to the stable layer.

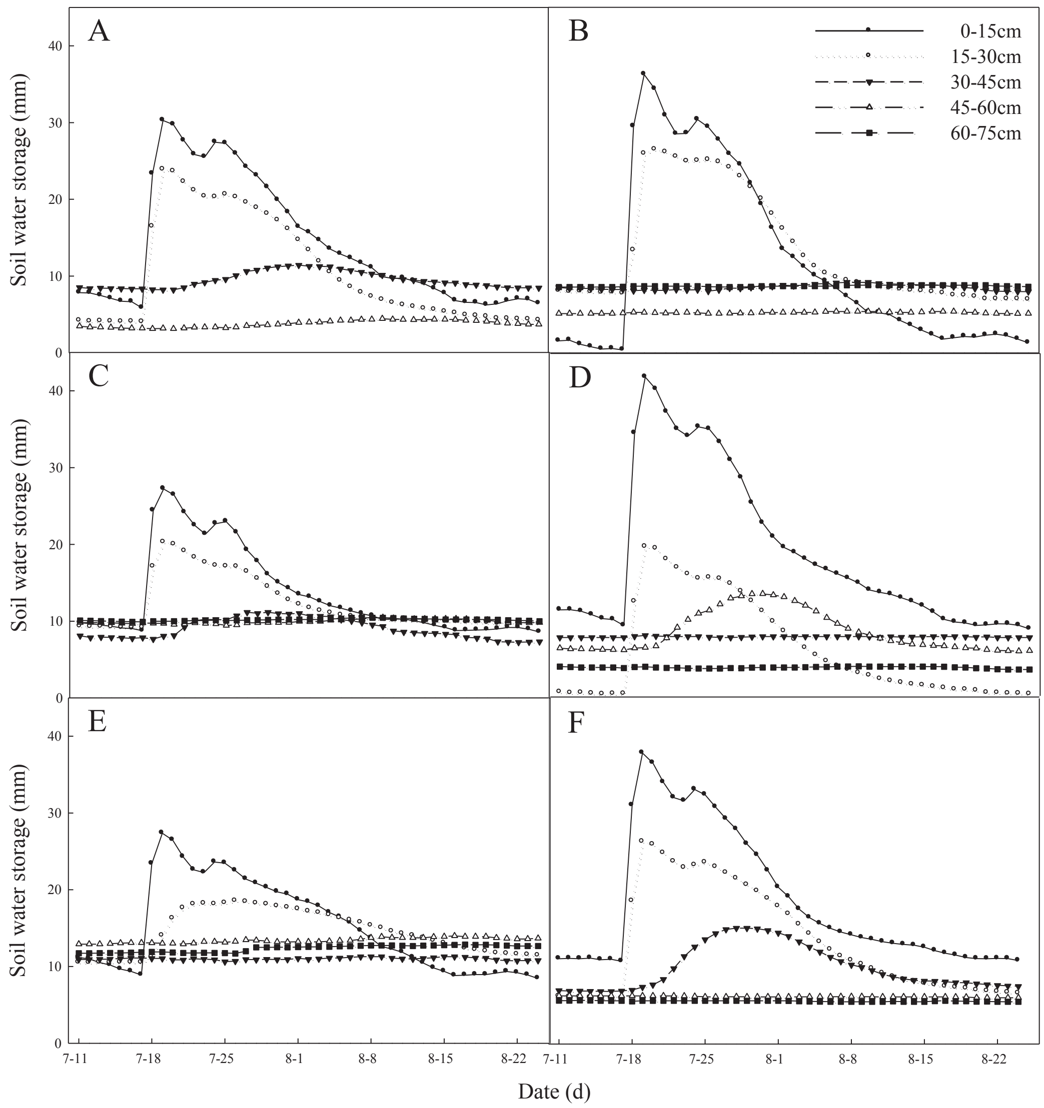

Fig.2 The vertical distribution of the soil water storage on the slope(A- upper slope sample without vegetation cover, the fifth layers of data loss, B- upper slope sample with vegetation cover, C- middle slope sample without vegetation cover, D- middle slope sample with vegetation cover, the second layers of data missing, E-lower slope sample without vegetation cover , F- lower slope sample with vegetation cover)

Soil moisture has a gradually increasing trend from the upper slope to the lower slope (Fig. 3). For samples without vegetation cover, soil water storage changed from 38mm in the upper slope to 54.7mm in the middle slope and to 66.2mm in the lower slope. There were no obvious changes for samples with vegetation cover. Soil water storage in the middle slope (44.6mm) was slightly less than that in the upper slope (47.1mm), and soil water storage in the lower slope of samples with vegetation cover was maximum (53.5mm). In the same slope position the standard deviation of the average storage of the samples with vegetation cover was bigger than that of no the samples with vegetation cover, which meant that the soil water storage in samples with vegetation cover fluctuated more significantly with time. The standard deviation of samples without vegetation cover decreased gradually from upper slope to lower slope while that of samples with vegetation cover had no significant change, which meant that the changes of soil water storage was smaller with lower slope.

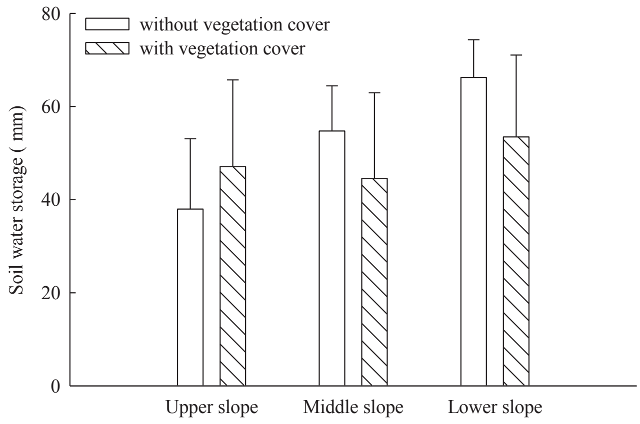

Fig.3 The average soil water storage of the slope

3.2 Evapotranspiration

Evapotranspiration is constituted by the soil evaporation and plant transpiration, among which plant transpiration is the one of plant physiological characteristics. There's only soil evaporation in samples without vegetation cover. Total evapotranspiration was gradually reduced from the upper slope to lower slope. In Fig. 4, evapotranspiration of samples without vegetation cover which gradually decreased from the upper slope to lower slope were 1.51mm / d, 0.92 mm / d and 0.69 mm / d respectively; three samples with vegetation cover have no significant difference among slope positions and evapotranspiration were 1.93 mm / d, 1.95 mm / d and 1.86 mm / d respectively.

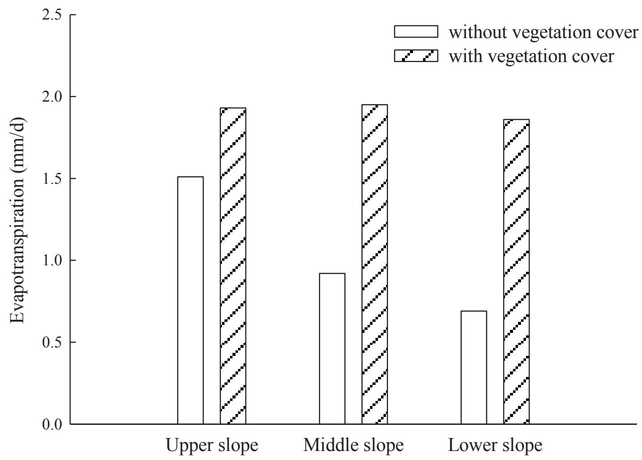

Fig.4 The evapotranspiration of the gradient from 7-26 to 8-24

3.3 Runoff

Since infiltration of soil moisture in the soil directly affects water movement, its permeability is related to the quantity of surface runoff generated and the amount of soil loss. Soil water storage is a direct reflection of the soil infiltration characteristics. The more soil water storage changes, the stronger infiltration capacity of the soil. When heavy rainfall occurred, the upper slope soil water storage increased most and it decreased from the upper slope to the lower slope (Fig. 5). According to the samples, large changes in samples without vegetation cover showed an obvious trend from the upper slope to the lower slope, the soil water storage were 44.2 mm, 28.8 mm, 21.8mm respectively. In samples with vegetation cover there's no obvious different increase of soil water storage between the upper slope and middle slope, respectively 54.4mm and 52.8mm. And soil water storage in lower slope was 42mm with relatively small increasing.

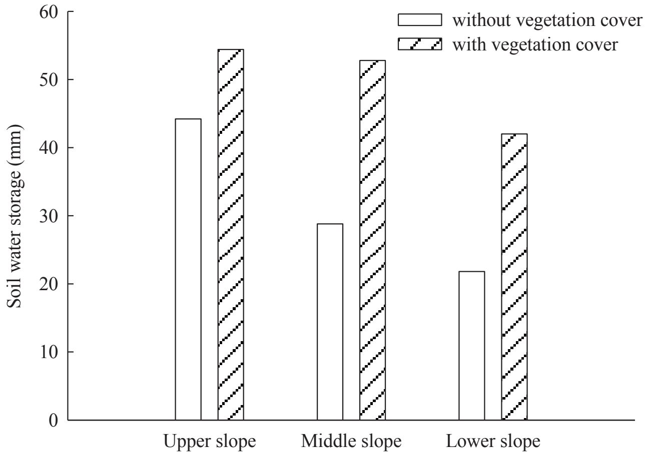

Fig.5 The increase of the soil water storage on the slope from 7-17 to 7-19

Runoff of the samples without vegetation cover gradually increased from the upper slope to lower slope and the largest runoff was 26.1mm in lower slope (Fig. 6). Runoff in samples with vegetation cover from the upper slope to lower slope gradually reduced and the maximum was 9.0mm. On the samples with vegetation cover, upper and middle slope positions were runoff input areas, while lower slope positions was runoff output areas.

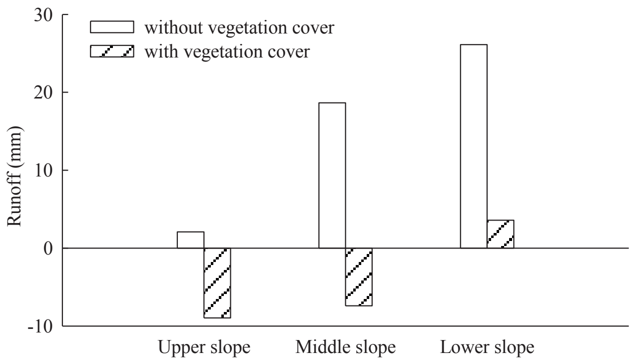

Fig.6 The runoff of the gradient after torrential rainfall(A positive value indicates runoff input and negative value indicates runoff output.)

4. Discussion

4.1 Slope position

Soil moisture gradually increases from the upper slope to the lower slope due to the accumulation effect of runoff [11]. Different precipitation and runoff led to difference in soil moisture of slope positions. Heavy rainfall increased soil water storage which reduced from the upper slope to the lower slope. It was because that the water storage in the0-30cm soil layer of samples without vegetation cover usually was small (Fig. 2), suggesting that larger soil particles would increase soil water infiltration, and vice versa. After rainfall, the water storage in upper slope increased significantly, especially in the 15-30cm layer.

In Fig. 4, evapotranspiration in A, C, E samples reduces from slope to lower slope. The upper slope had higher evaporation mainly because of the higher porosity of the larger particles, which were left during runoff processes while finer particles were washed away. Runoff carried a flow of fine particles from soil surface of the upper slope, and from the upper slope to lower slope soil particles increased. In the upper slope, large soil particles and porosity induced stronger soil water evaporation. Relatively lower slope with smaller soil particles and porosity resulted in small soil water evaporation. And soil water evaporation of middle slope was between that in the upper slope and lower slope.

Fig. 8 shows negative correlation between the initial soil water storage and the increasing amount after rainfall. The less the initial soil water storage, the larger the scarcity value of soil moisture, and soil water storage also increased more significantly. In the samples without vegetation cover, precipitation mostly transferred into increasing soil water storage and runoff. For samples at the same slope position, the evapotranspiration of samples with vegetation cover was more than that of samples without vegetation cover. Scarcity value of soil moisture was larger and water storage increased significantly in the event of rainfall.

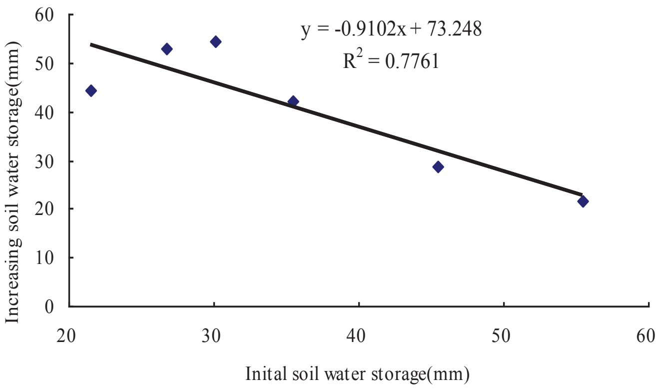

Fig.7 The relationship between initial and increase soil water storage with the torrential rains at the gradient

4.2 The impact of vegetation on soil moisture

Vegetation transpiration will disturb the soil water variability from the upper slope to lower slope including change trend according to slope positions which only appeared in soil evaporation. For the B, D, F samples, difference of vegetation growth led to unobvious change of evapotranspiration in samples with vegetation cover from the upper slope to the lower slope (Fig. 4).

Because of the low coverage in the samples without vegetation cover, rills easily formed on the bare surface and the runoff increased as well. With high flow velocity, the residence time was short [17]. Vegetation roots have the function of loosening soil, accelerating the water infiltration both in the quantity and velocity. Therefore the increasing amount of soil water storage in the samples with vegetation cover was obviously higher than the same in the ones without vegetation cover. (Fig. 6), besides, the water infiltration in the 15-30cm layer experienced a notable increase when the soil water storage in the 0-15cm layer increased (Fig. 5). In the samples with vegetation cover, the increasing amount of soil water storage gradually decreased from the upper slope to the lower slope since the degree of the upper slope was greater and along with more runoff (Fig. 5)

Not only because of more runoff in the upper slope, but also the generally lower soil water storage and higher scarcity value of soil moisture, the increasing amount of soil water storage and runoff input were both more remarkable. (Fig. 7). Runoff in lower slope was less because of relatively smooth topography, large initial soil water storage and less runoff input from upper slope after rainfall.

5. Conclusion

The soil water storage and evapotranspiration were gradually increased from the upper slope to lower slope, especially in the samples without vegetation cover. In samples with vegetation cover, the trend became weak because of the plant effects;

There's negative correlation between initial soil water storage and surface runoff caused by rainfall. When rainfall occurred, the increase of soil water storage in the upper slope was maximum, gradually decreasing from the upper slope to the lower. Because soil water storage normally gradually decreased from the upper slope to lower slope so that soil water deprivation level decreased. In the event of rainfall excess runoff occurred. Runoff increased from the upper slope to lower slope in samples without vegetation cover which were runoff output areas. However, runoff decreased from the upper slope to lower slope in samples with vegetation cover in which the upper and middle slope positions were runoff input areas and lower slope positions were runoff output areas.

Acknowledgments

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