Dynamics and response mechanism to precipitation of farmland soil moisture

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Abstract. Soil moisture (SM) plays an important role in the eco-hydrological processes in the sandy land, and hence is a critical ecological limiting factor. We analyzed the farmland SM dynamics and its response to precipitation based on the 0~160 cm SM and precipitation data from April 17 to September 15 in 2015, Horqin Sandy Land. The preliminary results shown that (1) During the experiment, the number of precipitation events was mainly <3.0 mm and accounting for 60.47% of the total precipitation events; And >15 mm occurred less and accounting for 4.65% of the total precipitation events, but its precipitation amount was relatively high (35.4 mm), accounting for 25.81% of the total precipitation. (2) With the increase of soil depth, SM firstly increased, then decrease, and finally increased again, and the SM of 40~60 cm and 140~160 cm soil layers were higher, while 0~20 cm and 100~120 cm were lower. (3) The SM was lower in April and September, and the seasonal variation of SM varies greatly depending on the soil depth. (4) After the different characteristic precipitation events, the SM of 0~60 cm and 120~160 cm continued to increase with the increase of soil depth, while the SM of 60~120 cm varied with soil depth showed a more complicated trend.

1. Introduction
In arid and semi-arid regions, soil moisture correlates with atmospheric precipitation, surface water, and groundwater. It plays an important role in the eco-hydrological processes and controls the formation and development of vegetation in the sandy land; hence, it is a critical ecological limiting factor [1-4]. The Horqin Sandy Land is one of the most severe desertification regions in China. Due to the impact of climate change and agricultural development in recent decades, the water resource constraints in the region have gradually become increasingly prominent. Frequent droughts have become an important issue affecting the desertification control process [5-6]. As an important water source for desert vegetation to maintain vital activities, soil moisture can meet the needs of crop growth only when it is reasonably and fully utilized [7]. In arid and semi-arid regions of the Horqin Sandy Land, atmospheric precipitation is the main source of soil moisture, and the intensity and frequency of atmospheric precipitation are important factors affecting the distribution of soil moisture in the soil profile [8].

Horqin Sandy Land has a fragile ecological environment; therefore, understanding the spatio-temporal dynamics of soil moisture in farmland and its response characteristics to precipitation is of great significance to the effective use and management of soil moisture in farmland, in this region. At present, there have been many studies on soil moisture in sandy land. For instance, He et al. [9]
studied the variation in soil moisture in shifting sandy land of the semi-arid regions and its dependence on precipitation; Zuo et al. [10] studied the spatial variability of soil moisture response to drought and precipitation in the sandy grassland of the Horqin Sandy Land; Huang et al. [11] and Yao et al. [12-13] studied soil moisture dynamics of different types of sandy land in the Horqin Sandy Land. However, most of these studies focused on the spatial and temporal distribution characteristics of soil moisture, and there are few studies on the dynamic characteristics of soil moisture in sandy farmland and the response characteristics of soil moisture to precipitation.

This paper combines the monitoring data of soil moisture in different soil layers of farmland in the Horqin Sandy Land with the precipitation data for the same period, and analyzes the seasonal dynamics and profile distribution characteristics of soil moisture in eight soil layers, with the aim to provide a comprehensive understanding of the soil moisture dynamics in the farmland of arid and semi-arid regions and the response mechanism of soil moisture to different precipitation characteristics, as well as guidance on the utilization of agricultural water resources and agricultural production in this region.

2. Material and methods

2.1. Study site description

The study area is located in Horqin Sandy Land, Naiman Banner, Tongliao City, Inner Mongolia, in Horqin Sandy hinterland (42°55′-42°57′N, 120°41′-120°45′E, altitude 340~370 m). This area has a semi-arid continental climate with annual average precipitation is 351.7 mm, the annual average evaporation is 1900 mm, and the annual average temperature is 6.5℃, and the frost-free period is 151 days. The landform is characterized by the staggered distribution of high and low dunes and gentle meadows or farmland, and the soil is mostly aeolian sandy soil or sandy meadow soil. The crop planted in the field research plot is corn.

2.2. Soil moisture monitoring and precipitation data acquisition

The soil moisture data used in this article comes from the comprehensive farmland observation field of the Naiman Desertification Research Station of the Chinese Academy of Sciences. We installed three neutron probes (CNC503DR) to record the soil moisture (%) of 0~160 cm, and one soil layer separated by 20cm. From Apr. 17 to 15 Sep. of 2015, the SM measured once every fifteen days and increased measurement after precipitation. The total measured times was 101 for each soil layer. The synchronize precipitation data (Daily precipitation) was received from nearby weather station.

2.3. Data processing

Data analysis and drawing were realized by Origin software.

3. Results and Discussion

3.1. Precipitation patterns

From 17 Apr. to 15 Sept. of 2015, 43 precipitation events were recorded, and amounted to 184.4 mm in total. Among these events, the minimum precipitation was 0.2 mm and the maximum was 24 mm. As the precipitation in the study area is dominated by small precipitation events, especially the precipitation events less than 3mm are the most frequent, while precipitation above 6mm rarely occurs, we classified the amount of precipitation into five levels: 0.1 to 3.0, 3.1 to 6.0, 6.1 to 10.0, and 10.1 to 15.0 and >15.0 mm. During the experiment, the number of precipitation events was mainly small precipitation event (<3.0 mm) (Figure 1), accounting for 60.47% of the total precipitation events; the number of occurrences of precipitation of 3.1~6 mm and 6.1~10 mm were 5 and 7, respectively, accounting for the total precipitation events 11.637% and 16.28% of the total precipitation, respectively; 10.1~15 mm and >15 mm occurred less frequently, accounting for 6.98% and 4.65% of the total precipitation events. In terms of precipitation distribution, the total precipitation of the five
orders is 25.4, 23.6, 52.4, 35.4, and 35.4 mm, accounting for 12.77%, 12.8%, 28.42%, 19.2%, and 25.81% of the total precipitation, respectively. In other words, although the number of occurrences of >15 mm is relatively small (accounting for 4.65% of total precipitation events), the amount of precipitation is relatively high. Among all precipitation events, the intensity was highest for precipitation >15 mm (23.8 mm d^{-1}), and was lowest for the 0.1–3.0 mm (0.98 mm d^{-1}).

\[ \text{Figure 1. Precipitation characteristics during the study period.} \]

3.2. Dynamics analysis of SM

3.2.1. SM changes with soil profile. The statistical characteristics of SM in different soil layers of farmland showed (Table 1) that, with the increase of soil depth, SM firstly increased, then decrease, and finally increased again. The SM of 40–60 cm and 140–160 cm soil layers were higher, while 0–20 cm and 100–120 cm were lower. The absolute value of the skewness of 40–60 cm was the largest, indicated that the SM of this soil layer was less than its average value, and the data was the most scattered. Kurtosis was the degree of expansion of the observations around the center point. The larger the value, the sharper the peak shape of the data distribution than the normal distribution [14]. It can be seen from Table 1 that the kurtosis of SM at 40–60 cm was the largest, indicated that the distribution peak shape of SM at 40–60 cm was much sharper than the normal distribution. The standard deviation and coefficient of variation of SM were larger in 0–20 cm, and smaller in 60–80 cm.

\[ \text{Table 1. The statistical characteristics of the SM (\%)} \text{ for the eight soil layers} \]

| Soil depth (cm) | Mean | Min. | Max. | SD | CV (\%) | Skewness | Kurtosis |
|----------------|------|------|------|----|---------|----------|----------|
| 0–20           | 17.65| 13.25| 21.77| 3.08| 17.43   | -0.21    | -1.38    |
| 20–40          | 24.61| 20.37| 29.15| 2.76| 11.20   | 0.00     | -1.19    |
| 40–60          | 33.81| 23.12| 36.85| 3.68| 10.88   | -2.09    | 4.67     |
| 60–80          | 27.50| 24.89| 29.40| 1.26| 4.58    | -0.60    | 0.09     |
| 80–100         | 26.56| 20.52| 31.98| 3.02| 10.58   | -1.59    | 2.50     |
| 100–120        | 24.76| 17.22| 30.48| 3.73| 15.05   | -0.40    | -0.24    |
| 120–140        | 28.86| 24.04| 33.64| 3.01| 10.43   | 0.01     | -1.22    |
| 140–160        | 34.56| 28.66| 37.04| 2.73| 7.91    | -1.57    | 1.32     |
| Mean           | 27.54| 21.51| 31.29| 2.91| 11.01   | -0.81    | 0.57     |

3.2.2. SM changes with season. The seasonal dynamic analysis of SM in farmland at different soil layer shown that the seasonal variation of SM varies greatly depending on the soil depth (except for
the 60–80 cm and 80–100 cm) (Figure 2). The SM was lower in April and September. Although there
was more precipitation in July, the SM in July did not increase significantly, mainly because the
temperature in July was higher, and strong soil evaporation and crop transpiration led to greater water
consumption [15]. In each month, the SM of 0–20 cm was the lowest, which was mainly due to the
stronger soil evaporation at the surface layer, while the SM of 40–60 cm and 140–160 cm was higher.

3.3. Response of SM to different characteristic precipitation

3.3.1. Different characteristic precipitation in the study period. Using the analysis results of
precipitation characteristics (such as precipitation amount, precipitation intensity, and precipitation
duration, etc.) during the test period (Figure 1), six continuous precipitation events with different
characteristics were selected to analyze the response of precipitation to SM. The six selected
precipitation events were in chronological order: May 10~May 12; Jun. 10~Jun. 13; Jun. 29~Jul. 4;
Jul. 19~Jul. 20; Aug. 9~Aug. 10; Sep. 11~Sep. 14. The precipitation characteristics were shown in
Table 2.

| Time (Month Day ~Month Day) | May 10~May 12 | Jun. 10~Jun. 13 | Jun. 29~Jul. 4 | Jul. 19~Aug. 10 | Aug. 9~Aug. 10 |
|-----------------------------|---------------|----------------|---------------|----------------|---------------|
| Duration of precipitation (d) | 3             | 4              | 6             | 2              | 2             |
| Precipitation amount (mm)    | 20.4          | 33.4           | 20            | 23.8           | 1.0           |
| Precipitation intensity (mm/d)| 6.8           | 8.35           | 3.33          | 11.9           | 0.5           |

3.3.2. Response of SM to different characteristic precipitation. We analyze the dynamic changes of
SM in farmland on the first day after the end of these six precipitation events to reflect the response
mechanism of soil moisture to precipitation, that was, the dynamic of SM at May 13, Jun. 14, Jul. 5,
Jul. 21, Aug. 11 and Sep. 15 by Figure 3. It can be seen that, at the first day after the end of these
precipitation events, the changing trend of SM with the soil depth was basically the same. The SM of
0–60 cm and 120–160 cm continued to increase with the increase of soil depth, making the SM of 60
cm and 160 cm reach two peaks, while the SM of 60–120 cm varied with soil depth showed a more
complicated trend: "first decreasing, then slightly increasing, and finally decreasing". From the perspective of changes in SM with soil depth after different characteristic precipitation events, the SM of 0–40 cm and 100–140 cm differ greatly after different characteristics of precipitation, while other soil layers were less affected by different characteristics of precipitation.

4. Conclusion
(1) The SM of 40–60 cm and 140–160 cm soil layers were higher, while 0–20 cm and 100–120 cm were lower, that was, with the increase of soil depth, SM firstly increased, then decrease, and finally increased again.
(2) The SM was lower in April and September and higher in Jun. and Jul.
(3) At the first day after the end of different characteristic precipitation events, the SM of 0–60 cm and 120–160 cm continued to increase with the increase of soil depth, making the SM of 60 cm and 160 cm reach two peaks; And the SM of 0–40 cm and 100–140 cm differ greatly after different characteristics of precipitation.

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