Variation of soil water content of fixed sand dune at 2014 in the Horqin sandy land

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Abstract. The fixed-point observation data of soil water content (SWC) in the growing season (from May to September) of 2014 in the semi-arid region of Horqin Sandy Land was employed to study the characteristics of SWC changes in fixed sand dune. The results showed that: 1) The SWC was relatively high in May. The SWCs in May and June were significantly higher than those in July, August and September, and were significantly different from those in July, August and September. From June to August, the SWC generally showed a decreasing trend. In September, the SWC did not recover obviously and remained at a low level. 2) The SWC was the lowest in the surface layer (0-10 cm), followed by the deep layer (90-150 cm), and highest in the shallow layer (10-90 cm), and there was a large difference among the three layers. The change of SWC with the soil depth showed a reversed S-shaped curve, i.e. “first increase, then decrease, and finally increase again”. The SWC was the highest (3.96%) in the soil layer of 30-50 cm, and the lowest (1.46%) in the soil layer of 0-10 cm. In the soil layer below 110 cm, the SWC showed a little change with the soil depth and tended to be stable.

1. Introduction

As a connecting link among the surface soil, vegetation and atmosphere, the soil water content (SWC) has received increasing attention from various related disciplines. Climate change, earth surface processes, weather forecast, floods, agriculture and water resource management all depend upon a correct understanding of SWC to a large extent [1]. SWC is an important ecological factor of sandy land ecosystems that determines the occurrence, evolution and productivity of sandy soil and restricts the vegetation formation and development in sandy land [2]. The dynamics of SWC and its spatio-temporal variability is an important part of the study on soil moisture in sandy land. The change of SWC in sandy land is not only affected by soil mechanical composition, terrain and vegetation, but also heavily reliant on the spatio-temporal variability of rainfall [3]. Therefore, it is significant to analyze the space-time heterogeneity of SWC and its response to rainfall [4]. There are many related studies on the dynamic changes of SWC and its relationship to rainfall [5-11]. For example Han et al showed that the SWC in Jiangxi had an obvious seasonal change, and was strongly affected by rainfall. The effects of rainfall on SWC decreased with soil depth [7]. The results of Yao et al indicated that the SWC of mobile sand dune differed significantly among the soil layers: mean SWC was greatest from 80 to 100 cm and lowest from 40 to 60 cm [8]. Gao et al obtained that there was a decreasing trend of the fluctuation amplitude of SWC with the increase of depth [9]. And Yao et al illustrated that SWC was higher in July, and significant difference with other month as influenced by rainfall; SWC was lower at 0-10 cm and significant different from other soil layer; and SW was higher at 10-30 cm [10]. Lan et al indicated that SWC increased with increasing soil depth in Loess Plateau [11]. But there was
few studies conducted on the characteristics of SWC changes with month and soil depths in sandy land rainfall.

The Horqin Sandy Land is a typical area of the farming-pastoral ecotone in northern China, and it is also one of the regions suffering from the most severe desertification in recent years. Recently, due to overgrazing, reclamation and continuous drought, sandy land ecosystems have degraded to varying degrees and land productivity has declined sharply, resulting in serious land desertification that has further exacerbated the already fragile ecosystem [12]. Desertification has led to obvious spatial variation of land surface features, which influences the functions and processes of the ecosystem through the redistribution of rainfall, reflecting changes in ecological functions and processes [13]. Thus, the study on the characteristics of SWC changes in fixed sand dune and its response to rainfall can not only help us understand spatio-temporal variations of SWC, but also have a significant effect on the further study of the ecological process of soil moisture, land productivity and management of sandy land ecosystems.

2. Materials and methods

2.1. Study area description
The study site is located in the southern part of the Horqin Sand land in eastern Inner Mongolia, China (42°55′ N, 120°42′ E, 345 m a.s.l.), with an average altitude of 360 m. This area belongs to the temperate semi-arid continental monsoon climate with an annual mean temperature of 6.4 °C, annual accumulated temperature above 10 °C of more than 3,000 °C and a frost-free period of about 150 days. Its annual mean rainfall is 364.6 mm, mainly concentrated in June-August, and annual mean evaporation is 1,972.8 mm. The main soil types include Aeolian sandy soil, meadow soil, sandy chestnut soil and swamp soil [14]. The climate is characterized by droughts and strong winds in winter and spring, rainfall concentrated in summer, and the water and heat in the same period, which is conducive to plant growth. The landform is characterized by the alternative distribution of fixed sand dune, semi-fixed sand dune, moving dunes and vast marshy grassland.

2.2. Data getting
In the study area, the typical fixed sand dune was selected as the experimental plot, where the main vegetation type was *Artemisia halodendron* and *Caragana microphylla*. Three 2m-deep neutron probes (CNC503DR) were buried at equal distances in the plot, and the soil volumetric water content (%) of 8 soil layers (including 0-10 cm, 10-30 cm, 30-50 cm, 50-70 cm, 70-90 cm, 90-110 cm, 110~130 cm and 130~150 cm) was recorded. The SWCs measured by the three neutron probes each time was averaged as the SWC of the plot. From May 5th to September 15th, 2014, the measurement was conducted once every 4~10 days and added after rainfall. The SWC of each soil layer was measured for 19 times. Rainfall data for the same period was obtained from the meteorological station of the nearby Naiman Desertification Research Station.

2.3. Data processing
Micro-Excel was used to process data and obtain statistical characteristics of SWC in different months and different soil layers. One-way ANDVA in SPSS 15.0 was used to test significant differences in SWC of different soil layers in different months. Micro-Origin 8.0 was used to plot the graph that shows the SWC changes with the month and soil depth.

3. Results and discussion

3.1. SWC changes with the month
Through the statistical analysis of rainfall during the experiment we found that the annual rainfall was 269 mm in 2014 which was mainly concentrated in May to September, accounting for 92.79% of the annual rainfall. According to the statistical characteristics of SWC in fixed sand dune from May to
September in 2014 (table 1), the average SWCs in different soil layers were higher in May and June (from 3.18% to 3.49%) and lower in July, August and September (from 2.4% to 2.99%); This was not consistent to the result obtained by Yao et al. This is mainly due to the large differences in seasonal distribution of rainfall in different years, and the SWC is mainly affected by rainfall [3]. The standard deviation and coefficient of variation were also significantly higher in May and June than in July, August and September. It indicates that higher SWC has stronger variability. The significance test of difference in SWC among different months showed that, the SWCs in May and June were significantly different from those in July, August and September, but the difference was not significant between May and June and between July, August and September.

| Month | Mean | Min. | Max. | S.D. | C.V. |
|-------|------|------|------|------|------|
| May.  | 3.18 | 1.56 | 4.87 | 1.09 | 0.34 |
| Jun.  | 3.49 | 1.27 | 5.41 | 1.38 | 0.40 |
| Jul.  | 2.99 | 1.40 | 3.99 | 0.80 | 0.27 |
| Aug.  | 2.54 | 1.92 | 3.02 | 0.41 | 0.16 |
| Sep.  | 2.40 | 1.14 | 2.88 | 0.58 | 0.24 |

Note: S.D. denotes standard deviation, C.V. denotes coefficient of variation. The difference letters in the second column indicates that there was a significant difference in soil water content between months, and the significance level was \( p = 0.05 \).

The changes of SWC and rainfall with the month (figure 1) showed that, the SWC in the soil layer of 90-150 cm did not change significantly with the month. On the whole, the SWC in May was relatively high, mainly due to heavy rainfall in May (79 mm) when the temperature was not high, the vegetation growth was in the initial stage and the evapotranspiration was weak, resulting in significant recharge of SWC from rainfall. From June to August, as the rainfall gradually decreased, the SWC in all soil layers (except for 0-10 cm) showed a decreasing trend, especially in the soil layer of 30-70 cm. Since the vegetation root layer of the fixed sand dune was mainly distributed in the soil layer above 70 cm [15], and this period was characterized by high temperature, vigorous vegetation growth, strong soil evaporation and vegetation transpiration, as well as low rainfall, the SWC was in a state of
depletion during this period. Although the rainfall increased to some extent in September, the SWC did not recover significantly and remained at a low level, indicating that when the SWC is continuously depleted, small rain intensity (<40 mm) cannot effectively replenish the soil moisture.

3.2. SWC changes with soil layers

According to the analysis on the statistical characteristics of SWC in different soil layers (table 2), the average SWC was high in the soil layer of 10-90 cm, varying from 3.08% to 3.97%; moderate in the soil layer of 90-150 cm, varying from 2.6% to 2.75%; and low in the soil layer of 0-10 cm, at 1.46%, this was consistent to the author's previous research results [10]. The SWC in the soil layer above 70 cm had larger standard deviation (SD) and coefficient of variation (CV), with SD varying from 0.31 to 1.2 and CV varying from 0.21 to 0.35; the SWC in the soil layer below 90 cm had smaller SD and CV, with SD less than 0.15 and CV less than 0.05. The results showed that the SWC above 70 cm had stronger variability, while the SWC below 90 cm had weaker variability. The significance test of difference in SWC among different soil layers showed that, there was no significant difference in SWC in the soil layer of 10-90 cm and 90-150 cm, respectively, but there was a significant difference between the two, and both were significantly different from that in 0-10 cm. The results showed that the SWC was the lowest in the surface layer (0-10 cm), followed by the deep layer (90-150 cm), and highest in the shallow layer (10-90 cm). And there were significant differences among the three layers.

| Soil depth (cm) | Mean | Min. | Max. | S.D. | C.V. |
|----------------|------|------|------|------|------|
| 0–10 cm        | 1.46 | 1.14 | 1.93 | 0.31 | 0.21 |
| 10–30 cm       | 3.09 | 1.92 | 4.31 | 1.08 | 0.35 |
| 30–50 cm       | 3.96 | 2.64 | 5.41 | 1.20 | 0.30 |
| 50–70 cm       | 3.74 | 2.88 | 5.35 | 0.99 | 0.26 |
| 70–90 cm       | 3.08 | 2.78 | 3.72 | 0.39 | 0.13 |
| 90–110 cm      | 2.69 | 2.58 | 2.90 | 0.14 | 0.05 |
| 110–130 cm     | 2.60 | 2.52 | 2.70 | 0.08 | 0.03 |
| 130–150 cm     | 2.75 | 2.60 | 2.98 | 0.15 | 0.05 |

Note: S.D. denotes standard deviation, C.V. denotes coefficient of variation. The difference letters in the second column indicates that there was a significant difference in soil water content between months, and the significance level was \( p=0.05 \).

The changes of SWC with the soil depth (figure 2) showed that, the change of SWC with the soil depth showed a reversed S-shaped curve, i.e. first increase, then decrease, and finally increase again, this was consistent to the previous research of the authors [10]. The SWC was basically the highest (3.96%) in the soil layer of 30-50 cm, and the lowest (1.46%) in the soil layer of 0-10 cm. In the soil layer below 110 cm, the SWC showed little change with the soil depth and tended to be stable. Among different months, the SWC in September showed the weakest variability with the soil depth, and the SWC in June showed the strongest variability. This is mainly due to the fact that vegetation growth generally stops in September, and vegetation transpiration consumes a very small amount of soil moisture. Meanwhile, the temperature in September is low, and the consumption of soil moisture through evaporation is also very low. Combined with low rainfall, both consumption and recharge of soil moisture are not obvious, leading to weak variability of SWC with the soil depth. On the contrary, the temperature rise, vegetation growth, strong soil evaporation and vegetation transpiration and increased rainfall in June led to strong variability of the SWC.
4. Limitation
The paper analysed the variation of soil water content with month and soil depth based on the
monitoring data from May to September in 2014 at fixed sand dune. Since the data is only one year,
the analysis method is relatively common, and the conclusion is not deep enough, the author's next
plan continuous monitoring the soil water content for many years in order to obtain more
comprehensive and in-depth analysis and to obtain more reliable and valuable conclusions.

5. Conclusions
- The SWC was relatively high in May and June, and there was significantly different from
  those in other months of the growing season. From June to August, the SWC generally
  showed a decreasing trend, and higher SWC has stronger variability.
- The SWC was the lowest in the surface layer (0-10 cm), followed by the deep layer (90-150
  cm), and highest in the shallow layer (10-90 cm), that was, the change of SWC with the soil
  depth showed a reversed S-shaped curve, i.e. first increase, then decrease, and finally increase
  again. And there was a significant difference among the three layers.

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