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Analysis of soil moisture condition under different land uses in arid region of Horqin Sandy Land, northern China

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Abstract

Land use plays an important role in controlling spatial and temporal variations of soil moisture by influencing infiltration rates, runoff, and evapotranspiration, which is substantive meaning to crop growth and vegetation restoration in semiarid environments, such as the Horqin Sandy Land in north China. However, few studies have been conducted comparing differences of dynamics of soil water conditions and the responses of soil water to precipitation infiltration under different land use types in this semiarid region. Five different land use types were selected to analyze soil moisture variations in relation to land use patterns during the growing season of two years. Results showed that soil moisture condition was affected by different land uses in semi-arid sandy land. The order of soil moisture (from high to low) among different land uses was grassland, cropland, poplar land, inter-dunes and shrub land. The temporal variations of soil moisture in different land uses were not always consistent with the rainfall due to the dry sequence. Moreover, soil water in surface, root zone and deep soil layer indicated statistical difference for different land covers. Meanwhile, temporal variations of soil moisture profile changed with precipitation. However, in deep soil layer, there was a clear lag in response to precipitation. In addition, seasonal variations of profile soil moisture were classified into two types: increasing and waving types. And the stable soil water layer was at 80–120 cm. Furthermore, the infiltration depth exhibited a positive correlation with precipitation under all land uses. This study provided an insight into the implications for land and agricultural water management in this area.

1 Introduction

In water-limited environments, soil moisture is one of the key factors impacting the crop growth and vegetation restoration (Ran et al., 2013; Zhang et al., 2004). However, soil moisture exhibits a tremendous heterogeneity in space and time even in small catchments (Gomez-Plaza et al., 2000). Therefore, spatial and temporal variations of

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soil moisture have always been the critical issues in vegetation restoration and water resource management in the semi-arid and arid ecosystems (Brevik et al., 2015; Yu et al., 2015). This variability of soil moisture results from the differences in topography (Svetlitchnyi et al., 2003), soils (Tomer and Anderson, 1995), vegetation (Vivoni et al., 2008) and land uses (Biro et al., 2013; Fu et al., 2003). A better understanding of the soil moisture variability is important for land management in runoff and erosion control that can drastically modify resistance of soil to environmental change and increase the vulnerability of semi-arid ecosystems (Alvarez-Romero et al., 2014; Fitzjohn et al., 1998; Gao et al., 2013; Huang et al., 2014; Martinez-Murillo et al., 2013).

Soil moisture plays a dual role in being both a cause and a consequence of the type of vegetation (Rodriguez-Iturbe, 2000). Soil moisture is the key variable linking soil characteristics to plants, thus vegetation communities will be associated with characteristic soil moisture regimes (Sandvig and Phillips, 2006). Cerdà (2000) reported that soil erodibility was greater under agricultural land use compared with scrubland under arid environments, indicating that cultivating the land under certain conditions might contribute to increasing soil erosion and runoff. Additional, Land use change may influence many natural phenomena and ecological process, including water runoff and erosion (Nunes et al., 2011), especially a significant impact on soil moisture (Haghighi et al., 2010). Many studies have explored the dynamics of soil moisture under different land use, including temporal and spatial distribution patterns (Chen et al., 2007; Wilcox and Newman, 2005). Li et al. (2009) showed that land use change from woodland to grassland decreased soil water by 18 % during 1981–2000 in an agricultural catchment of the Loess Plateau, established by simulation results using soil and water assessment tools. Clearly, studying on spatio-temporal field soil water variations under different land use types is critical for agricultural water management and land erosion control (Gao et al., 2014; Starr, 2005; Ziadat and Taimeh, 2013).

Moreover, Land use can affect precipitation infiltration, which is of great importance to vegetation restoration and crop production in semi-arid areas (Wang et al., 2008; Ziadat and Taimeh, 2013). Infiltration is the movement of water into the soil from the

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surface by downward or gravitational flow (Thompson et al., 2010; Zhang et al., 2010). It is the feedback between the infiltration of water from precipitation and the water use characteristics of the particular vegetation community that ecologically predominates in an area that determines the moisture state of the soil in the root zone (Sandvig and Phillips, 2006). Some studies have shown that plant biomass and productivity increased significantly with increasing soil infiltration rates, which have close relationships with covered vegetation types (Benegas et al., 2014; Finley and Glenn, 2010; Fu et al., 2015; Zhang et al., 2014; Zheng et al., 2015). In addition to types and coverage degrees of vegetation (Cerdà, 1998; Molina et al., 2007), precipitation patterns (Wang et al., 2008), antecedent soil water content (Guo et al., 2014) and soil properties (Neris et al., 2012) also play the influential role in the water infiltration process.

Horqin Sandy Land is located in the semi-arid environmental region of northern China. Due to the long-term influences of human activities (e.g., extensive firewood consumption, heavy grazing and land reclamation for agriculture) and climate changes (e.g., changes of precipitation regimes and temperature), this region has suffered serious desertification over recent decades, resulting in the scattered tree grassland to be the Horqin sandy grassland (Zuo et al., 2009). To date, most sandy grassland have degenerated into fixed, semi-fixed, semi-mobile and mobile sandy lands (Liu et al., 2009; Zuo et al., 2009). Spatio-temporal variations of soil water result in the changes of community composition and vegetation pattern (Dunkerley, 2000; Ravi et al., 2010; Snyder and Tartowski, 2006; Sperry and Hacke, 2002; Zuo et al., 2009). Researchers have focused on the dynamics of soil water conditions and the responses of soil water to precipitation infiltration under the land-surface processes in this region (Huang et al., 2012). However, previous studies have investigated that spatial and temporal variation of soil water under a certain land use type, and drawing significant research attention is lacking on the differences of dynamics of soil water conditions under different land use types. Thus, it is necessary to understand the comparisons of the dynamics of soil water conditions under different land use types in Horqin Sandy Land, which is not only laid the foundation for the effective use of water resources, but also plays an important role in the land productivity evaluation and desertification recovery in this region.

The overall aim of this paper was to describe how sandy soil moisture respond to different vegetation types among different land uses types in Horqin Sandy Land. The specific objectives of this study were: (1) to examine patterns and dynamics of soil moisture under different vegetation types, (2) to analyze differences in vertical soil moisture distribution as well as the influence of precipitation on profile soil water for different land uses.

2 Materials and methods

2.1 Study site

This study was conducted in Ulan'aodu Station in the west of Horqin sandy land (43°02′ N, 119°39′ E), northeast of China. Ulan'aodu Station, built in 1975 and affiliated with the Institute of Applied Ecology of the Chinese Academy of Sciences, is one of the monitoring network stations of the Department of Desertification Control, State Forestry Administration of China. The elevation of this region is about 480 m, and the climate is temperate, semiarid continental and monsoonal and is characterized by less precipitation and frequent occurrence of strong winds. The mean annual precipitation is 284.4 mm, of which 70 % occurs from June to August. The mean annual open-pan evaporation ranges from 2000 to 2500 mm. The average aridity index is 1.99, the relative humidity varies between 50 ∼ 55 %, and drought is serious in the spring. The mean annual temperature is 6.2 °C, annual frost-free period is 140 d and the mean annual wind velocity is 4.2 m s^{-1}. The landscape is characterized by gently undulating, mobile, semi-mobile, and fixed sand dunes with inter-dunes bottomlands (Alamusa et al., 2014). Soil texture consists of aeolian sandy soil, meadow soil and saline soil. Flora mainly consists of Mongolia flora, North China flora and Changbai flora, where the most widely distributed species are plants of Mongolian flora.

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2.2 Experimental design

Five typical land use types were selected to be research plots in Horqin sandy land, including woodland (Poplar), shrub land (*Caragana korshinskii kom)*, grassland (fenced grassland), farmland (maize) and inter-dune lowland, respectively (Fig. 1).

Poplar land was located in the flat sandy land with 400 m × 600 m area sixteen years ago. The plant density was 1.5 m × 2.0 m and the average height and diameter was 22.6 m and 16.3 cm, respectively. Herbaceous and litter were observed on the ground.

Grassland was located in the flat sandy land with the overall area of about 6000 acres without shrubs and arbor. The community was mainly composed by perennial grass, including *Calamagrostis epigejos* and *Spodiopogon sibiricus Trin* with the average height of 52.6 cm.

Cropland was located in the flat sandy land based on the grassland decades years ago, where the main crop was annual maize with fertilization during growing seasons but without irrigation in the whole seasons.

Inter-dunes research plots were selected between fixed sandy dunes and mobile sandy dunes with 400 m × 500 m area. The vegetation species consisted of *Agriophyllum squarrosum, Calamagrostis epigejos, Salix flavida, Potentilla chinensis, Caragana korshinskii kom* and so on.

Shrub land was mainly located in the dunes based on mobile dunes, which were one or three consecutive dunes area between 400–600 acres. *Caragana korshinskii kom* community land was selected as the shrub land with a slop of 30°, which was planted by 1.0 m × 1.5 m at 23 years ago, and the average height and crown was 1.8 and 2.2 m, respectively.

Measured vegetation cover and soil properties were shown in Table 1 for different land uses.

Precipitation and potential evaporation were measured at meteorological station in Ulan'aodu. Precipitation of June, July and August was higher than the other months in 2002 and 2003, and evaporation was always higher than precipitation each month;

moreover, based on the meteorological data recorded in previous years, the annual precipitation from June to August was over 70 % of the whole year, and the annual evaporation (2300 mm) was 6.6 times of precipitation (Fig. 2).

2.3 Methods

The research plots were set in the center of five types of land uses with 20 m × 20 m, and 5 sample plots (4 m × 4 m) were set randomly in each type of five land uses. A sample point was designed at each plot for measuring soil moisture at depth of 0–120 cm and profile was divided into 0–20, 20–40, 40–60, 60–80, 80–100 and 100–120 cm at 20 cm increments and 3 repetitions each layer and soil moisture was measured through drying method. The measuring time was from 15 April to 15 October in 2002 and 2003 with 15 days interval.

The groundwater table was observed using groundwater observation well in each area of land uses. The groundwater table was at 1.6–3.5 m in poplar land, inter-dunes, grassland and cropland based on the flat sandy land in these plots. While, the groundwater table was over 8 m in shrub land based on mobile dunes with a slope of 30° approximately. In addition, on the basis of the root surveys, distribution zones of plant roots were generally soil layers of 0–80 cm in this environmental regions. Therefore, soil layers of 0–20, 0–80 and 80–120 cm were defined as surface horizon, root zone and deep soil layer, respectively. In this study, surface soil water was the value of 0–20 cm soil water; root zone soil water was the mean value of 0–20, 20–40, 40–60 and 60–80 cm soil water; and deep layer soil water was the mean value of 80–100 and 100–120 cm soil water (Gao et al., 2014).

To indicate the infiltration depth of rainfall and its effects on vertical soil moisture changes, we measured soil water at the day (1–2 days) before rainfall events, after rainfall events (1–2 days), and before the next rainfall events, respectively. Considering the hysteresis of rainfall infiltration process, soil water was measured with an interval of days after rainfall events. The lengths of time intervals were dependent on the precipitation; in general, the larger the amount of precipitation, the longer the time interval.

Four types of rainfall were selected to evaluate vertical soil water changes derived from precipitation events in 2002 (Gao et al., 2014).

First, the low rainfall was taken from 2.6 mm precipitation event on 24 April 2002. To show profile soil water variations for five land uses, soil water was observed at 0–120 cm on 23, 25 April 2002.

Second, the medium rainfall was taken from 16.2 mm precipitation events on 9 and 10 June 2002. To indicate profile soil water variations for five land uses, soil water was measured at 0–120 cm on 8, 11 June 2002.

Third, the high rainfall was taken from 40.5 mm precipitation events on 11–13 July 2002. To explore profile soil water variations for five land uses, soil water was surveyed at 0–120 cm on 11, 15 July 2002.

Forth, the extreme-high precipitation was taken from 102.4 mm precipitation events on 4, 5, 6 August 2002. To explore profile soil water variations for five land uses, soil water was observed at 0–120 cm on 3, 15 August 2002.

In order to distinguish the effect of precipitation on soil water changes, the absolute differences were calculated between soil water content at 0–120 cm intervals after precipitation and that before precipitation for each land use. We hypothesized that the absolute difference was defined as a significant change resulting from precipitation infiltration if it was positive and more than 0.5 %, or else, was defined as a stochastic change (Gao et al., 2014).

2.4 Data analysis

Statistical analysis were performed to test the influence of land use on soil moisture using one-way ANOVA, and comparisons of the difference between mean water content in different land uses were implemented using the least significant difference (LSD) method (at the $p < 0.05$ level). The analysis were conducted through SPSS Statistics v17.0 Copyright© 2008 SPSS Inc.

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3 Results

3.1 Temporal variations of soil water in different land uses

3.1.1 Temporal variations of mean soil water within 0–120 cm in different land uses

The temporal variations of mean soil water content during growing season were shown in Fig. 3. First, the temporal variations of soil moisture showed a trend of two peaks pattern both in 2002 and 2003. The first and the second peak appeared at June and August, respectively. The poplar land soil moisture content was increasing after rainfall and was consistent with the temporal variations of rainfall. Second, grassland soil water variations showed two and three peaks in 2002 and 2003, respectively, and the peaks appeared at May, August and May, July, September, respectively, which was not synchronous with the rainfall temporal variations. Third, cropland showed two peaks at May and September, respectively, which was not concurrent with the rainfall in 2002; the only peak appeared at August due to the lack of relevant data in 2003, which was accordant with rainfall. Forth, the inter-dunes soil water variations showed two peaks at the beginning of June and August, which was consistent with rainfall changes; inter-dunes soil moisture showed a decreasing trend in 2003. Moreover, shrub land soil water variations showed single peak both in 2002 and 2003, and appeared in July and June with a value of 2.42 and 2.38 %, respectively, which was consistent with rainfall.

3.1.2 Temporal variations of soil water profiles in different land uses

Variations of soil water profiles changed with time and were dependent on rainfall (Fig. 4a–c). Under different land uses, trends of soil surface water varied with the changes of precipitation patterns (Fig. 4a). Soil surface water of each land use patterns presented higher soil moisture content during the peak of precipitation between July and August. For example, soil surface water of grassland reached a peak value

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(14.78 %) in August 2002 when a heavy rainfall event (112.6 mm) happened. However, soil water presented a complicated variation in root zone (Fig. 4b). For example, soil water of five land uses patterns presented an increasing trend in August 2002 due to the heavier rainfall. In the contrary, soil water presented a decreasing trend from June to September when heavier rainfall still continued during this period. There were no obviously changes in deep soil layers under different land uses with the changes of precipitation (Fig. 4c), and deep soil water presented a smooth temporal change during the whole growing season.

3.2 Profile variations of soil water content in different land uses

3.2.1 Comparisons of vertical soil water in different land uses

Significant differences were observed among three layers for the five land uses patterns (Table 2). First, the soil water content of grassland was significantly ($p < 0.05$) higher than that of the other land uses patterns in comparison of surface soil water, while, in cropland and poplar land, surface soil water was markedly higher than that of inter-dunes and shrub land. But, there were no considerable differences on soil surface moisture between inter-dunes and shrub land. Second, the soil moisture of grassland was also remarkably higher than the other land uses patterns in root zone, while the shrub land was evidently lower than that in the other land uses patterns. Furthermore, the soil water of grassland and inter-dunes were conspicuously higher than the other land uses patterns in deep soil layer, while shrub land was significantly lower than the other land uses patterns in deep soil layer, too.

3.2.2 Seasonal patterns of vertical soil water in different land uses

In spring (Fig. 5a), soil water in different land uses, except cropland, exhibited a low-high-low variation trend with the depth from 0 to 120 cm and the peak values appeared at 60 cm (grassland), 110 cm (inter-dunes and poplar land) and 40 cm (shrub land) with the value of 13.55, 17.09, 11.17 and 2.80 %, respectively. However, soil moisture variations in cropland showed an increasing trend from 0 to 120 cm. In summer (Fig. 5b), soil moisture variations in poplar land, grassland and inter-dunes showed a single peak with depth increasing, and the peak value appeared at 90, 90 and 110 cm, respectively. Meanwhile, in cropland and shrub land, soil water variations exhibited two peaks and the peak values appeared at 60, 110 cm and 20, 110 cm, respectively. In autumn (Fig. 5c), all the land uses soil moisture variations were observed similar stable trend with depth increasing, except for grassland whose soil moisture showed relatively smooth trend at 0–100 cm and gradually declined from 16.15 % at 100 cm to 3.09 % at 120 cm.

3.3 Influences of precipitation infiltration on vertical soil water changes for different land uses

The situation of soil water infiltration after four rainfall events was different for five land uses (Table 3). The soil water at 0–20 cm of all five land use patterns responded significantly increasing after light (2.6 mm) and medium (16.2 mm) rainfall. After a heavy rainfall event (40.5 mm), a significant increasing trend in soil water was observed at 0–60 cm. Remarkably, the whole profile (0–120 cm) soil water was supplied by a heavier rainfall event (102.4 mm).

Different land uses showed different responds to the four types of rainfall. Under the light rain condition, the order of incremental soil water (from high to low) was grassland, cropland, inter-dunes, shrub land and poplar land at 0–20 cm depth, and the incremental soil water of grassland was the most obvious than the others. Similarly, under the medium rainfall condition, the order of incremental soil water (from high to low) was grassland, cropland, inter-dunes, poplar land and shrub land at 0–20 cm, and the highest incremental value of grassland was 5.08 %. Moreover, under the heavy rainfall (40.5 mm), the incremental soil water order (from high to low) at 0–60 cm was grassland, cropland, poplar land, inter-dunes and shrub land. Furthermore, under the

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extreme heavy rainfall (102.4 mm), the incremental soil moisture order (from high to low) was grassland, cropland, poplar land, inter-dunes and shrub land at 0–120 cm.

4 Discussion

4.1 Soil moisture variability for different land uses

4.1.1 Temporal variations of mean soil moisture within 0–120 cm

The variations of mean soil moisture in different land uses were not always consistent with the rainfall (Fig. 3). This is because the "dry" sequence (the term dry sequence is defined as a succession of several consecutive days without rain preceded and followed by days with rain) appeared (Fu et al., 2003), although several small rain events occurred in July 2002 and 2003, they did not interrupt the dry trend. Further, the moisture content reaching peak value corresponded to the amount of precipitation, and that the higher mean moisture contents appear after heavier rain. However, there were differences in response to the rain due to land uses. For example, the peak in mean soil moisture content for cropland in 2002 and poplar land in 2003 showed a lag effect following a rain event (Fig. 3), because of the interception by canopy and the buffering influence of groundcover.

Moreover, the temporal variations of soil moisture profile changed with precipitation (Fig. 4). Surface (0–20 cm) soil water for all different land uses correlated positively with precipitation events (Fig. 4a); in root zone (0–80 cm), soil water showed a complicated trend due to evapotranspiration (Fig. 4b). There are two potential explanations. First, the effects of the root distribution on soil moisture may contribute to this difference (Sala et al., 1992). Second, vegetation possibly transforms the soil physical properties, such as soil bulk density, physical composition, and porosity (Garcia-Ruiz, 2010). These changes, in turn, influence the infiltration rate, storage, and redistribution of soil water

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(Lipiec et al., 2006). However, the deep soil layer (80–120 cm) had a relatively smooth temporal change, a clear lag in response to precipitation.

Under different land uses, although, the temporal variations of soil water in surface, root zone, and deep soil layer were observed following rainfall patterns, similar temporal evolutions of soil water at different profiles existed (Fig. 4). This implied that land use influenced on spatial patterns however insubstantial on temporal variations of soil water (Gao et al., 2014). Accordingly, precipitation was the main factor that affected soil water and brought similar trend on temporal patterns for different land uses. Therefore, land use was the main reason that affected the spatial variations, and precipitation was the main factor that influenced the temporal patterns, which was consistent with the recent findings from Yao et al. (2012).

4.1.2 Profile variations of soil moisture in different land uses

There is a significantly difference on the surface (0–20 cm) soil water among different land uses (Table 2). This is not consistent with the results that showed variations of 0–20 cm soil water in different land uses were low over the growing seasons in the hilly area of the Loess Plateau (Chen et al., 2007). A possible explanation is that the regional differences (Gómez-Plaza et al., 2000).The differences in topography, soils, vegetation and land uses resulted in the variability of soil moisture (Fu et al., 2003). Moreover, soil surface moisture of grassland was significantly higher than the other land uses ($p < 0.05$), because of the higher clay content (Table 1) and the high water holding capacity of the surface soil. And soil surface moisture of inter-dunes was significantly lower than the other land uses, because of the poor permeability result from heavy clay soil, and the effective water content was low (Li et al., 2010). Also, there were statistical differences ($p < 0.05$) of soil water in both root zone and deep soil layer for different land uses (Table 2). This may be the result of different evapotranspiration patterns due to various distributions of plant root under different land uses (Gao et al., 2014).

Clearly, the profile of soil moisture indicated distinct vertical patterns for various seasons (Fig. 5). In spring, two types were classified as increasing and waving types,

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which based on soil moisture changes with depth. Cropland showed the increasing type, likely due to the low evapotranspiration in spring (Qiu et al., 2011; Stéfanon et al., 2014; Yang et al., 2014) and the loose soil characteristic for rainfall infiltrating. The waving type consisted of poplar land and shrub-land, grassland and inter-dunes, where soil moisture presented a low-high-low change in profile. A possible explanation was the different soil bulk density and root distribution.

Moreover, in summer, soil moisture in the poplar land, grassland, and inter-dunes presented a low-high-low change with depth, while the cropland and shrub land presented a low-high-low-high-low change, likely due to the different evapotranspiration of different vegetation (Li et al., 2009; Wagendorp et al., 2006).

Furthermore, soil moisture showed a stable (high-low-high-low) trend with wave-changing type at 0–120 cm except grassland in autumn (Fig. 5c). Grassland soil moisture gradually decreased with depth from 100 to 120 cm, which was not consistent with the recent findings (Gao et al., 2014). The possible reason was the differences in topography, which was the main factor controlling time stability (Gómez-Plaza et al., 2000).

4.2 Differences in soil moisture and infiltration among land cover types

In general, the infiltration process is controlled by precipitation patterns, ground cover, soil characteristics, slop and initial soil moisture (Gabarrón-Galeote et al., 2013; Gómez-Plaza et al., 2000; Wang et al., 2013), which in turn affects soil water.

In our study, the amount of medium precipitation was 6.2 times that of low rainfall, however the increase of soil water after medium precipitation was only 1.2 times that after low precipitation. The part of reason is that vegetation just begin to come into leaf in the early growing season (low precipitation), and that plants can intercept part of precipitation with thick branches and luxuriant foliage in mid-June (medium precipitation) (Gao et al., 2014). This is consistent with the result reported by Wang et al. (2005) that shrub community (*C. korshinskii kom*) canopy interception was 11.7 % of the precipitation. Furthermore, the study suggested that infiltration depth increased with the

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increase of precipitation, indicating that infiltration depth will be greater than 120 cm after heavier precipitation (Table 3). Similarly, Yao et al. (2013) reported that infiltration depth increased with increasing precipitation amount. Notwithstanding a positive correlation was indicated between precipitation and infiltration depth, it is difficult to quantify the relationship due to the varying initial soil water content, rainfall intensity, vegetation cover, and meteorological conditions among the four precipitation events (Gao et al., 2014).

Moreover, vegetation affecting on precipitation interruption for soil was to influence soil water by changing precipitation and soil properties (Li et al., 2013). In our study, there were no obvious differences on infiltration depth after four types of precipitation intensity, but the incremental soil water was different in different land uses. Under the low rainfall condition, incremental soil water of poplar land was smaller than that of the other land uses. The possible reason was that the vegetation canopy and litter interrupted precipitation to enter into soil. Furthermore, under other three types of precipitation, incremental soil water in shrub land (*C. korshinskii kom*) was smaller than that of the other land uses. The first reason was that soil water runoff was strong on shrub land due to the effect of slope (Adekalu et al., 2007) and the second reason was that shrub community was set up on mobile dunes where the soil evaporation was intense and vegetation cover was low. In the contrary, higher vegetation cover of other land uses prevented from direct solar radiation to surface soil and high clay (Table 1) led to higher water-holding capability.

Furthermore, land type of inter-dunes had a higher soil bulk density and clay content (Table 1), leading to a slow infiltration rate, and the incremental soil water was smaller than cropland, poplar land and grassland (Fig. 3). Therefore, it could maintain a high soil water level for a long time, which contributed to the growing herbaceous plants. From discussed above, both grassland and inter-dunes could maintain higher soil moisture, where are beneficial for the stable development of plant community in this landscape.

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4.3 Implications for soil and water conservation

In the semi-arid and arid land, precipitation regimes have influenced by climate changes (Parry et al., 2007). This will aggravate water conditions, leading to serious desertification. Therefore, it is vitally important for making efficient use of the limited water resources to improve the ecological environment and agricultural water management in these regions (Gao et al., 2014).

Due to cropland could induce severer soil erosion and land degradation, keeping implementation of artificial forest and natural rehabilitation was still a key initiative to restrain desertification in Horqin Sandy land (Zhang et al., 2012). In addition, soil moisture would decline in *C. korshinskii kom* shrub land for the reason soil water could not get the supplement from the deep soil water resulting from *C. korshinskii kom* had deep and enormous roots for water uptake (She et al., 2013). Moreover, water consumption of poplar was higher than grassland vegetation (Kang et al., 2008), and deep soil layer could be dry and deteriorate due to precipitation interruption and deep-root water uptake (Wang et al., 2013). Consequently, this would result to competitive disadvantage of deep-rooted arbor and shrub. If this situation continued, "low-thin-old-trees" and further degradation might occur (Zhao et al., 2009). In the light of high soil moisture maintained in grassland and inter-dunes, herbaceous plant is likely to be an adaptive and stable vegetation type under this environmental condition.

Furthermore, catchment water balance and the factors that affected water balance were influenced by different land uses. Dai et al. (2006) reported that land use was the main factor that affected water balance and evapotranspiration was the largest expenditure in land water balance. Moreover, comparison (from high to low) of the evapotranspiration in different land uses was cropland, arbor, shrub land and grassland (Kang et al., 2008). In addition, our study indicated that surface soil moisture exhibited relatively low values ($< 5\,\%$) during growing season (May–July) (Fig. 4a). Thus, an irrigation scheme must be worked out to meet water requirement and then increase soil water utilization according to soil water content and evapotranspiration.

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To conclude, during the process of vegetation recovery in arid region, we should analyze more detail about spatial and temporal variations of soil water for different land uses and the factors that affected soil water of different vegetation, and took reasonable management from the point of efficient use of water to keep water balance and stable vegetation community development.

5 Conclusions

Different land uses was the main reason that contribute to the soil moisture variations. The temporal variations of mean soil moisture in different land uses were not always consistent with the rainfall due to the dry sequence. The cropland and poplar land showed a lag effect following a rain event due to the canopy interception and the buffering influence of groundcover. Moreover, soil water in surface, root zone and deep soil layer indicated statistical difference under different land covers. Meanwhile, the temporal variations of soil moisture profile changed with precipitation; there was a clear lag in response to precipitation for deep layer soil water. Two types for the seasonal variations of soil moisture profile in five land uses were classified and the stable layer of soil moisture was found at 80–120 cm. Moreover, a positive correlation existed between precipitation and infiltration depth for all land uses. Those results give us an insight into land and water management, an irrigation scheme must be worked out to meet water requirement and then increase soil water utilization during the initial growth of crop, which could also decrease severer soil erosion and land degradation. Grassland represented more adaptive vegetation in this area. Therefore, the local government should establish fenced meadow and decrease grazing properly to protect natural grassland and plant trees with the reasonable density in the flowing sandy land and inter-dunes land.

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Table 1. Vegetation and soil characteristics at 0–20 cm for the five land uses in study area.

Land use	Land cover type (plant species)	Canopy cover percent (%)	Buck density ($g\,cm^{-3}$)	Soil texture	
				Sand percent (> 0.01 mm)	Clay percent (< 0.002 mm)
Poplar land	*Populus davidiana*	78	1.32	87.3	12.7
Grassland	*C. epigejos* and *S. sibiricus Trin*	90	1.23	80.85	19.15
Cropland	*Zea mays*	86	1.19	93.05	6.95
Inter-dunes	*A. squarrosum, C. epigejos, S. flavida,* and *P. chinensis*	80	1.55	84.7	15.3
Shrub land	*C. korshinskii kom*	65	1.46	94.5	5.5

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Table 2. Multiple comparisons for mean water content at different layers of five land uses.

Land use	Soil water content (%) Surface (0–20 cm)	Root zone (0–80 cm)	Deep layer (80–120 cm)
Poplar land	3.77b	5.97b	12.1b
Grassland	11.54a	12.55a	21.65a
Cropland	3.72b	6.68b	9.06bc
Inter-dunes	1.66c	4.32c	14.37ab
Shrub land	1.93c	1.95d	1.86c
P value	< 0.001	< 0.001	0.00781

P value refers to the probability of same soil water values of analysis of variance in the 95 % percent significance level. Values in each column with the same letter are not significantly ($p < 0.05$, LSD) different among land uses.

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Table 3. Soil water variations (%) for different depth at 0–120 cm after four precipitation events.

Precipitation event	Low (2.6 mm)					Medium (16.2 mm)				
Soil depth (cm)	Poplar	Grass	Crop	Interdunes	Shrub	Poplar	Grass	Crop	Interdunes	Shrub
0–20	**0.55**	**4.75**	**1.34**	**0.71**	**0.64**	**0.85**	**5.08**	**1.83**	**0.76**	**0.69**
20–40	−0.07	−0.14	−0.06	−0.08	−0.02	−0.05	−0.31	−0.9	−0.59	−0.15
40–60	0.03	−0.15	−0.06	−0.09	−0.07	−0.05	−0.03	−0.99	−0.12	−0.13
60–80	−0.1	−0.07	−0.04	−0.13	0.09	−0.01	0.15	−0.03	−0.2	−0.03
80–100	−0.05	−0.04	−0.01	−0.04	−0.05	−0.01	−0.02	−0.02	−0.12	−0.01
100–120	−0.03	0.01	−0.01	−0.01	−0.02	−0.01	−0.01	0.01	0	0
Incremental (%)	0.58	4.75	1.34	0.71	0.64	0.85	5.08	1.83	0.76	0.69
Precipitation event	High (40.5 mm)					Extreme high (102.4 mm)				
Soil depth (cm)	Poplar	Grass	Crop	Interdunes	Shrub	Poplar	Grass	Crop	Interdunes	Shrub
0–20	**1.85**	**5.13**	**2.58**	**1.92**	**1.25**	**2.98**	**4.83**	**3.95**	**2.33**	**2.18**
20–40	**0.68**	**3.77**	**1.9**	**1.63**	**1.02**	**2.82**	**3.72**	**2.41**	**2.21**	**2**
40–60	**0.56**	**1.45**	**0.96**	**0.41**	**0.35**	**2.52**	**3.2**	**2.37**	**2.15**	**1.35**
60–80	−0.29	−0.97	−0.65	−0.68	0.04	**2.33**	**2.46**	**2.17**	**2.36**	**1.29**
80–100	−0.06	−0.04	−0.08	−0.06	−0.02	**1.57**	**2.11**	**1.88**	**2.03**	**1.06**
100–120	−0.01	0.01	−0.01	0	−0.01	**1.05**	**1.93**	**1.44**	**1.65**	**1.78**
Incremental (%)	3.09	10.35	5.44	3.96	2.58	13.27	18.25	14.22	12.73	9.66

The values in the table represent the absolute difference between soil water content after rainfall and that before rainfall. Significant changes are bold, and negative values represent soil water content decreases.

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Figure 1. Land use types and soil water sampling points in the experiment area.

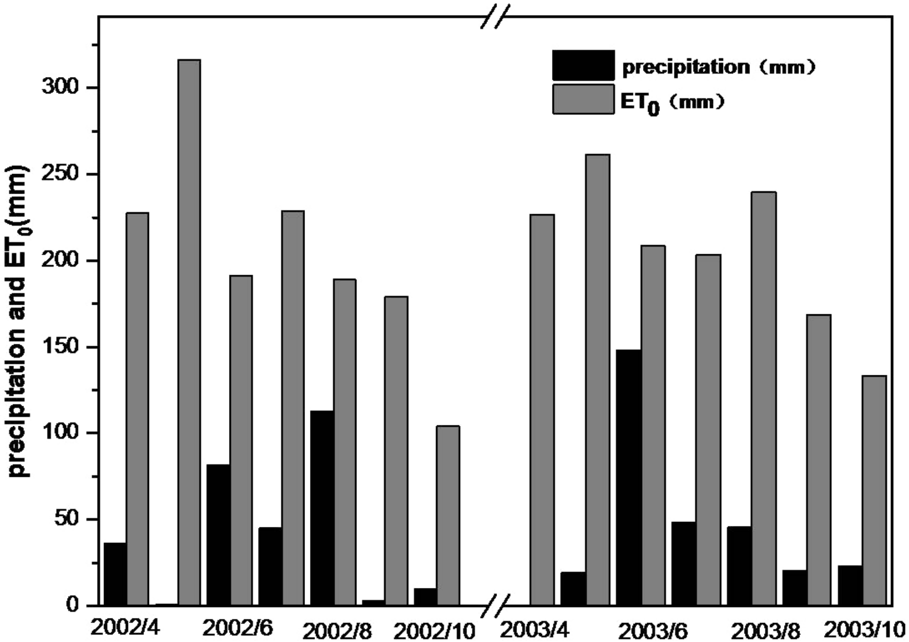

Figure 2. Monthly precipitation and potential evapotranspiration (ET_0) during the study period.

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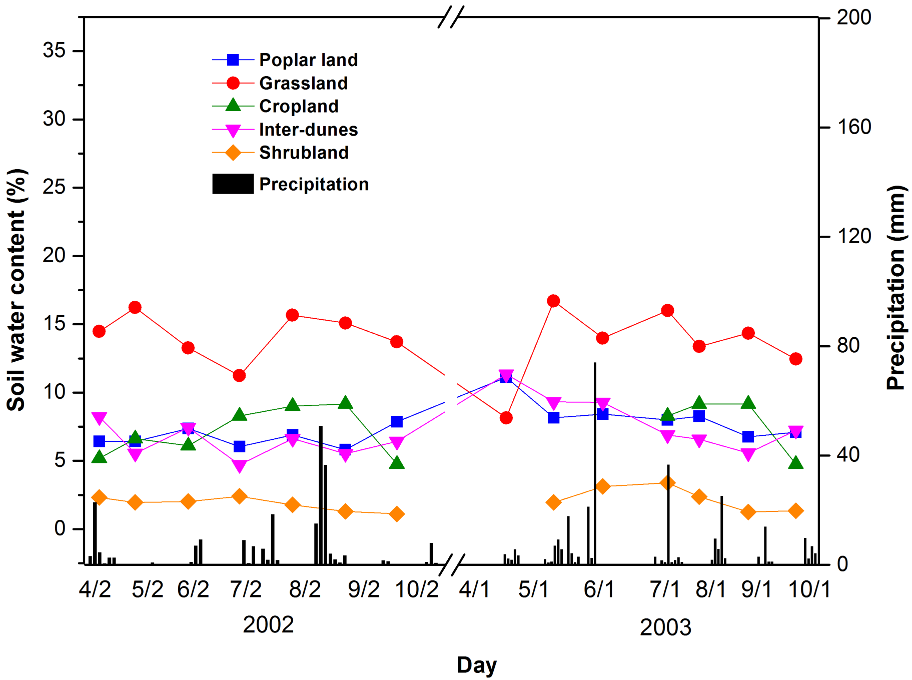

Figure 3. The temporal variations of mean soil moisture within 0–120 cm in five land uses.

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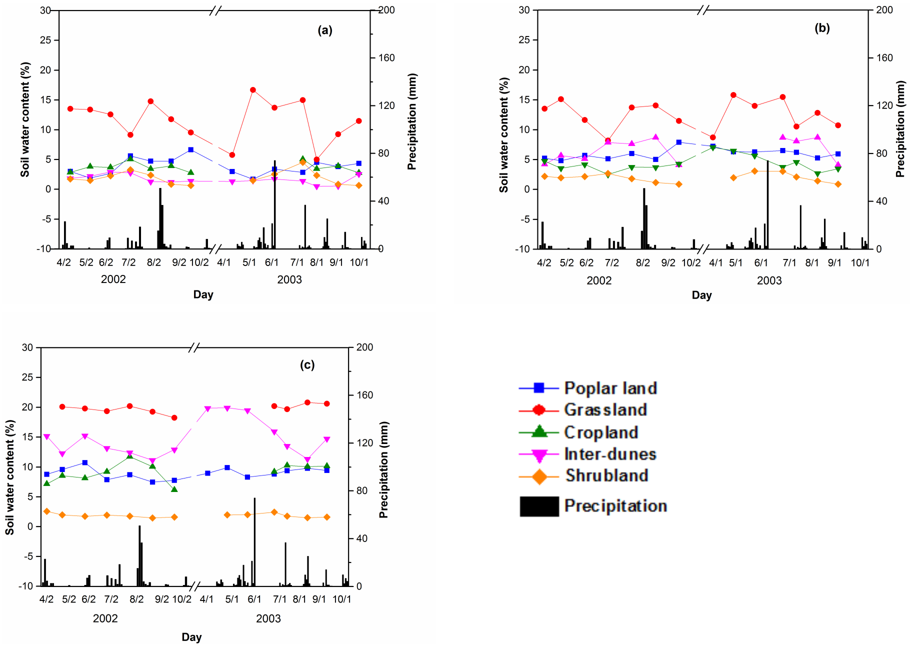

Figure 4. Temporal variations of soil water content for surface horizon **(a)**, root zone **(b)** and deep soil layer **(c)** in different land uses.

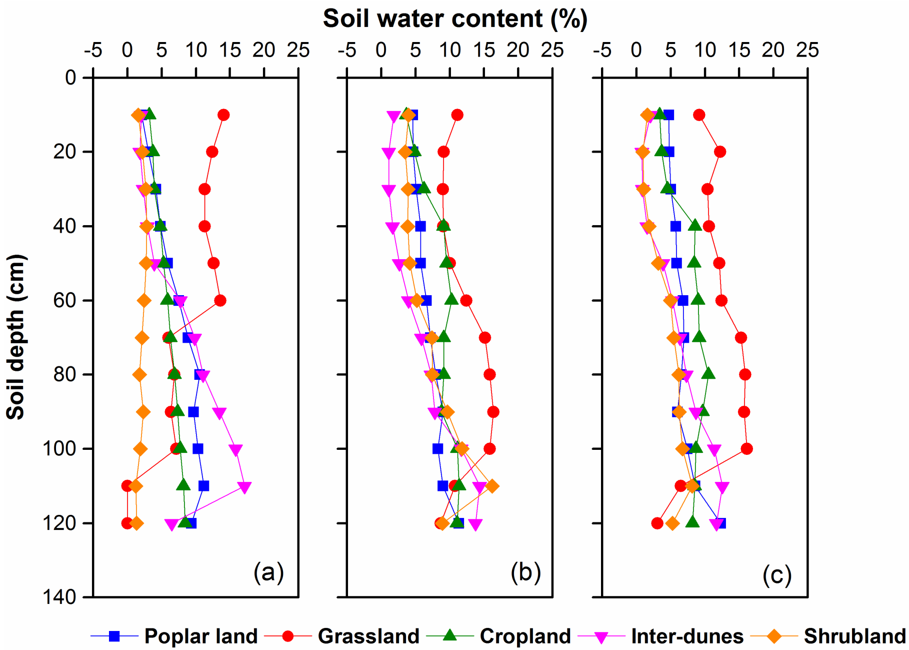

Figure 5. Seasonal patterns of vertical soil water variations for different land uses: spring **(a)**, summer **(b)** and autumn **(c)**.

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