Effects of artificial grassland type on soil water content of degraded land restored by ecological measures in suburban Beijing

Zhuo Pang, Tiejun Sun, Haiming Kan and Juying Wu

Research & Development Center for Grass and Environment, Beijing Academy of Agriculture and Forestry Sciences, No. 9 Middle of Shuguang Garden Road, Haidian District, Beijing, China, 100097

Email: wujuying@grass-env.com; pangzh-84@163.com

Abstract. Establishment of artificial grasslands is an effective and economic measurement for restoring degraded land, however, established grasslands consume soil water and disturb local water balance as well. To quantify the influence of artificial grasslands on soil water content, we monitored soil volumetric water content (VWC) at depths of 5 cm, 10 cm, 15 cm, 20 cm and 25 cm in artificial grasslands of Bromus inermis Leyss and Medicago sativa continuously throughout 2018. For Bromus inermis Leyss grassland, VWC peaked at depth of 20 cm (0.190±0.053 m³·m⁻³) and varied little among the rest depths, while for Medicago sativa grassland, VWC increased with depth and the highest value was 0.153±0.047 m³·m⁻³ at depth of 25 cm. Moreover, VWC in Bromus inermis Leyss grassland was obviously higher than that in Medicago sativa grassland for the whole year at depths of 5 cm, 15 cm and 20 cm, and slightly higher for part of the year at depth of 10 cm, but insignificantly lower at depth of 25 cm. As for water conservation, Bromus inermis Leyss grassland could perform better than Medicago sativa grassland. Under the identical climatic and edaphic conditions, the dramatic differences in VWC between grasslands of Bromus inermis Leyss and Medicago sativa imply that ecohydrological response should be taken into consideration, when selecting measures for ecological restoration.

1. Introduction
Degraded land will cause severe environmental problems, such as, sand storm, soil erosion, water pollution, biodiversity decline, etc. [1]. As an international metropolis, Beijing’s rapid urbanization during the last few decades has resulted in land degradation and accompanying decline in ecosystem services for the urban and suburban areas [2–4]. To offset the environmentally negative effects of degraded land on Beijing’s development, it is urgent to realize land degradation neutrality by ecological restoration [5-7].

Pytoremediation is an attractive and effective methodology for land restoration and soil remediation, especially the establishment of artificial grassland [8]. With appropriate site-specific agronomic practices, the tolerant grasses or other plant species can grow and survive on degraded or contaminated land. Furthermore, together with their associated microbiomes, grasses or other plant species can remediate multiple pollutants or enhance soil organic carbon content, and achieve restoration of degraded land [9].
Grassland establishment generally is able to enhance and improve ecosystem services, however, soil water overconsumption by grasses might be a potential threat to the sustainability of regional development [10-12]. As a result, effects on soil water content are a key factor for selection of plant species when restoring degraded land with ecological measures [10]. Due to impacts on infiltration rates, runoff and evapotranspiration, vegetation type definitively regulates soil water content, and the regulations of soil water content are different for vegetation types, not only between tree forests and grassland in Guangdong, but also between different types of grassland in the Loess Plateau[11, 12].

To assess the effects of artificial grassland restoring degraded land on soil water content in suburban area of Beijing, we monitored and compared soil volumetric water content (VWC) of two kinds of grassland continuously.

2. Material and methods

2.1. Site description
The study was carried out in Zhangshanying Town Yanqing District, which is the suburban area of Beijing City, the upstream catchment of Guanting Reservoir, and near the competition zone of Yanqing for the 2022 Olympic and Paralympic Winter Games (Figure 1).

Figure 1. Location of the study site.

The artificial grasslands of *Bromus inermis* Leyss and *Medicago sativa* for restoration of degraded land were established in 2014 and adjacent to each other. After establishment, the grasslands were left to develop naturally with little human interference. The soil layer had a depth of ~30 cm for both grasslands.

2.2. Data measurement and analysis.
Soil volumetric water content (VWC) was measured in grasslands of *Bromus inermis* Leyss and *Medicago sativa* simultaneously throughout 2018. The soil moisture probes of 5TE (Meter Group, USA) were inserted into soil horizontally at depths of 5 cm, 10 cm, 15 cm, 20 cm and 25 cm to measure VWC and soil temperature. VWC was measured at a frequency of once per ten minutes and the data were collected and stored in EM50 datalogger. The daily rainfall was measured by a rain gauge on a nearby weather station.

The VWC data downloaded from EM50 dataloggers were firstly merged into hourly and daily data sets. Then the data were plotted chronologically to compare between depths and between grassland types with the help of Excel.
3. Results
Soil water is replenished by rainfall and consumed by vegetation. As a result, soil volumetric water content (VWC) will change with rainfall event, soil depth and vegetation type, etc.

3.1. Rainfall trend
Rainfall exert substantial impact on soil water conditions of artificial grasslands restoring degraded land, as there is no irrigation. For the year of 2018, the amount of precipitation was 463.6 mm. There were 56 rainy days, among which 41 were light rain (i.e., daily rainfall lower than 10 mm), 10 were moderate rain (i.e., daily rainfall between 10 mm and 25 mm), and 5 were heavy rain (i.e., daily rainfall between 25 mm and 50 mm). The heaviest rain occurred on Jul. 21st, with an intensity of 45 mm/day (Figure 2).

For the study area, rainfall concentrated between June and September (Figure 2). From Jul. 1st to Sep. 30th, the accumulated rainfall was 354.9 mm, accounting for 76.6% of the annual total. Moreover, there were 35 rainy days, with 9 days of moderate rain and 4 days of heavy rain, within this period.

![Figure 2. Trends of daily rainfall.](image-url)

3.2. The trends of VWC with time and soil depth
Yearly the VWC change can be divided into two periods. One was from Match to September, when the VWC varied violently accompanied by grass growing season and frequent rain events (Figure 2, 3 and 4). The other was from October to February of the next year, when the VWC remained stable with grass dormancy and negligible precipitation (Figure 2, 3 and 4). For the period from Match to September, the staged average of VWC was higher than the annual average of VWC (moist period), while for the period from October to February of next year, the staged average of VWC was lower than the annual average of VWC (dry period) (Figure 3 and 4). The soil in dry period subjected to small water input and output, however, soil in moist period relatively large water input (rainfall) and output (evapotranspiration).

VWC in both types of grassland was generally controlled by heavy rain events and drought duration. Through 2018, there were 3 VWC peaks occurring on May 18th, Jul. 22nd and Aug. 15th (Figure 4). The first two VWC peaks appeared on the day immediately after the days of May 17th and Jul. 21st with heavy rain (33.9 mm and 45 mm), indicating the saturating effect of heavy rain to various soil depths in both grasslands (Figure 2, 3 and 4). While for the last VWC peak, as there is a lasting drought period from Jul. 24th to Aug. 7th with no precipitation and a moist period from Aug. 8th to Aug. 14th with continuous rainy days (Figure 2), the heavy rain on Aug. 8th did not generate a VWC peak and the dehydrated soil delayed the VWC peak for one week (Figure 2, 3 and 4).
Figure 3. Soil water content at different depths for artificial grassland of *Bromus inermis* Leyss.

Although trends of VWC are similar between grasslands of *Bromus inermis* Leyss and *Medicago sativa* chronologically VWC changes with soil depth are quite different between the two types of grassland (Figure 3 and 4).

Figure 4. Soil water content at different depths for artificial grassland of *Medicago sativa*.

Yearly, the VWC of *Bromus inermis* Leyss grassland fluctuated between 0.122±0.037 m³⋅m⁻³ and 0.190±0.053 m³⋅m⁻³ at various soil depths, with the peak value appeared at 20 cm and the minimum value at 10 cm (Figure 3). While the VWC of *Medicago sativa* grassland increased slowly and steadily with depth from 0.082±0.039 m³⋅m⁻³ at 5 cm to 0.103±0.035 m³⋅m⁻³ at 20 cm (with an average increasing rate of 0.0014 m³⋅m⁻³⋅cm⁻¹) but increased dramatically to 0.153±0.047 m³⋅m⁻³ at 25 cm (Figure 4).

In *Bromus inermis* Leyss grassland, the variation of VWC was largest at 5 cm (0.134±0.062 m³⋅m⁻³) and smallest at 25 cm (0.144±0.033 m³⋅m⁻³) (Figure 3). However, in *Medicago sativa* grassland, the variation of VWC was similar among different depths, with the smallest at 20 cm (0.103±0.035 m³⋅m⁻³) and the biggest at 25 cm (0.153±0.047 m³⋅m⁻³) (Figure 4).
3.3. Differential of VWC between the two types of artificial grassland

Grasslands of Bromus inermis Leyss and Medicago sativa had distinct impacts on soil water conditions, which were exhibited explicitly by trends of soil volumetric water content (VWC) at different depths (Figure 5) and summary of VWC values (Table 1).

![Figure 5. Comparison of soil volumetric water content (VWC) at different depths between two types of artificial grassland.](image)

At depth of 5 cm, VWC was obviously higher and more variable in Bromus inermis Leyss grassland than in Medicago sativa grassland, especially for moist period (Figure 5). At depth of 10 cm, VWC in Bromus inermis Leyss grassland was slightly higher than that in Medicago sativa grassland for dry period, but was close to each other for the moist period (Figure 5). At depths of 15 cm and 20 cm, VWC in Bromus inermis Leyss grassland was significantly higher than that in Medicago sativa grassland for the whole year, however, the heavy rain events in July, August and September narrowed the differences to some extent (Figure 5). At depth of 25 cm, VWC had no difference between the two types of grassland for dry period, and VWC in Medicago sativa grassland was insignificantly higher than that in Bromus inermis Leyss grassland (Figure 5).

Table 1. Summary of soil volumetric water content (VWC) for all depths. a

| VWC (m$^3$·m$^{-3}$) | Grassland types | Bromus inermis Leyss | Medicago sativa |
|---------------------|------------------|----------------------|-----------------|
| Dry period b         | 0.104 (0.011)$^d$ | 0.074 (0.007)        |
| Moist period c       | 0.177 (0.032)    | 0.127 (0.035)        |
| Entire year          | 0.147 (0.044)    | 0.105 (0.038)        |

a Including depths of 5 cm, 10 cm, 15 cm, 20 cm and 25 cm. b From October to February of the next year. c From March to September. d Average (standard error).
Summarily, VWC of topsoil (0-25 cm) in *Bromus inermis* Leyss grassland was higher than that in *Medicago sativa* grassland for dry period, moist period and entire year (Table 1). Moreover, the variations of VWC for both types of grassland in moist period were larger than those in dry period (Table 1).

4. Discussion
Under the circumstances of identical rainfall input, soil water content is primarily determined by vegetation types. Soil water volumetric water content (VWC) in *Medicago sativa* grassland is lower than that in *Bromus inermis* Leyss grassland in this study, especially at depths of 15 cm and 20 cm and there could be two possible mechanisms behind this result. Firstly, low soil temperature in *Bromus inermis* Leyss grassland caused by bigger vegetation coverage increases water viscosity and root resistance, and hence water uptake by roots is reduced [13]. Secondly, soil water on the profile of *Medicago sativa* grassland might be redistributed due to hydraulic redistribution. Roots of *Medicago sativa* as a taproot system would compensate the drier layer at the shallow depth (i.e., 10 cm depth) by transferring water from moister layers (i.e., 15 cm and 20 cm depths) [14, 15], and hence VWC in *Medicago sativa* grassland is close to that in *Bromus inermis* Leyss grassland at 10 cm depth but significantly lower than that in *Bromus inermis* Leyss grassland at depths of 15 cm and 20 cm.

Vegetation type has a strong effect on soil water dynamics [16, 17]. Due to effects of rainfall interception by canopy and water uptake by deep roots, distribution of soil water content in tree forests is highly heterogeneous spatially and is distinct from adjacent grasslands in moist area[12, 18, 19]. Even within grasslands, different types of grassland also have quite different influences on soil water content under the same climate and soil conditions, and one example is that natural grassland of *Stipa bungeana* Trin. has higher soil water content than artificial grassland of *Medicago sativa* L. in semiarid Loess Plateau [11]. The bifurcating effects of different types of grasslands on soil water content are confirmed in this study as well. As a result, effects on soil water conditions must be taken into consideration when selecting vegetation type for ecological restoration, especially for areas where water resource is limited.

5. Conclusions
Compared with *Medicago sativa* grassland, *Bromus inermis* Leyss grassland consumes less water and conserves more water in soil layer. For the purpose of water conservation, it could be better to select *Bromus inermis* Leyss rather than *Medicago sativa* for grassland establishment, when restoring degraded land in Beijing and similar water-limited areas.

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