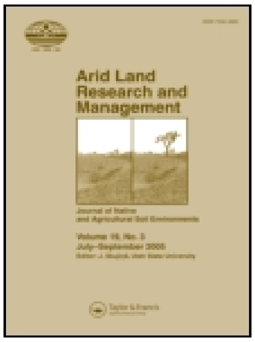

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Soil Moisture Variability under Different Land Uses in the Zhifanggou Catchment of the Loess Plateau, China

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Soil moisture is an important variable that determines crop growth and vegetation restoration. In the Loess Plateau, China, soil moisture dynamics are dramatically affected by land use patterns. This study investigated seven-year soil moisture dynamics and vertical distribution under seven land use patterns. The soil moisture levels in the 0 to 300 cm depth in two croplands, and those in 0 to 600 cm depth in two shrublands, a forestland, a grassland, and an abandoned cropland for natural recovery were measured in late April and late October of 2004 to 2010. The soil moisture storage in the 0 to 300 cm depth in the Zea mays *cropland dramatically exceeded that in the other six land use patterns. The* Caragana korshinskii *shrubland and* Robinia pseudoacacia *forestland exhibited the lowest soil moisture storage in the entire 0 to 600 cm depth. The soil moisture storage in the* Hippophae rhamnoides, Caragana korshinskii, Robinia pseudoacacia, *and* Medicago sativa *lands showed a decreasing tendency, whereas that in the abandoned cropland was almost stable. Rainfall recharged the entire 300 cm soil profile in the two croplands. The maximum soil infiltration levels in the* Hippophae rhamnoides, Caragana korshinskii, *and* Robinia pseudoacacia *lands were 200, 200, and 240 cm. The results indicate that planted shrubs and forests deplete soil moisture in the deep soil profile. The construction of terraces and dams can improve precipitation utilization rate, and restoring native grasslands after abandonment may be the best option for vegetation rehabilitation in the Loess Plateau.*

Keywords inter-annual change, land use, Loess Plateau, soil moisture, soil moisture storage

Soil moisture is a major influencing factor for many hydrological processes, especially runoff generation, soil evaporation, and plant transpiration. It also exhibits comparatively large variability in space and time (Owe et al., 1982; Grayson et al., 1997). The spatio-temporal variations in soil moisture are influenced by topography (Burt & Butcher, 1985; Western & Bloschl, 1999; Wilson et al., 2005), precipitation and climate (Famiglietti et al., 1998; Yoo et al., 1998), soil type (Hawley et al., 1983), vegetation (Roux et al., 1995; Ursino & Contarini, 2006), and land use and land cover (Fu et al.,

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2000, 2003). Land use and land cover strongly influence the soil moisture dynamics in the Loess Plateau, China (Chen et al., 2007). The Loess Plateau is located in arid and semi-arid areas, and is currently undergoing tremendous changes in land use and land cover because of a project aimed at converting farmland back to forestland and grassland. This project and its effects have been investigated by several researchers, who confirmed that unreasonable land use practices dry out soil. The results of these studies have indicated that the changes in land use patterns observed in the Loess Plateau significantly influence the hydrologic cycle. The consequences of such changes on the water balance and the possible reduction in aquifer recharge have generated increasing research attention (Li, 1983; Huang et al., 1999; He et al., 2003). Different land uses exert various effects on soil moisture conditions. Thus, comparing the distinctive effects of land uses on soil moisture is critical to successful vegetation restoration in the Loess Plateau.

The effects of land use on soil moisture variability have been extensively investigated. In the Loess Plateau of China, many studies had been done to study the seasonal changes in soil moisture and vertical soil moisture distribution across different land uses (Zhang et al., 2006; Wang et al., 2013). The authors found that there are mainly three types of soil moisture changes take place in the profile: increasing, decreasing, and fluctuating changes (Yang et al., 2001; Fu et al., 2003), the vertical distribution of soil moisture differed in different seasons and the variability of surface soil moisture was strongly influenced by soil texture (Gao et al., 2011). The loss of soil moisture occurs primarily during the vegetation growth season and the lost soil moisture cannot be completely replenished by precipitation during the rainy season, thereby inhibiting the sustainable growth of vegetation in the Loess Plateau (Chen et al., 2007). Meanwhile, a number of scholars have evaluated long-term soil moisture variability under different land uses. Wang, Liu, & Dang (2009b) examined the effects of major vegetation types on soil moisture and the effects of inter-annual changes in soil moisture on the Loess Plateau. In Southern Italy, Longobardi (2008) researched the soil moisture temporal patterns and variations of a perennial lawn grass land, and discovered that the annual soil moisture cycle was obviously affected by inter-annual precipitation fluctuation, and intra-annual precipitation fluctuation mainly impact soil moisture dynamic during the dry period of the year. From October 2004 to December 2008 Venkatesh et al. (2011) studied soil moisture variability at 50, 100, and 150 cm depths in three land use types, namely, an acacia plantation, a natural forest, and a degraded forest. The authors noted that although different vegetation cover types, to some extent, cause variations in soil moisture, topographical elements are the core factors that affect soil moisture. A number of researchers have also studied soil moisture storage under different land uses. Natural rainfall had a significant impact on the soil moisture storage in the Loess Plateau (Jiang et al., 2007), and regional rainfall levels can compensate for water consumption in soil layers at a depth of 180 cm (Dong et al., 2011). Although substantial research has been conducted on the seasonal changes in soil moisture storage capacity and soil moisture variability under different land uses, little attention has been paid to the long-term soil moisture storage and soil moisture variability under different land uses in the Loess Plateau.

The present study investigated the seven-year soil moisture variability in seven land uses. Our objectives are as follows: (a) to investigate the dynamic changes and its inter-annual changes of soil water storage under different land uses and (b) to study the vertical distribution characteristics of soil moisture and rainfall recharge depths under different vegetation patterns. We hypothesized that the shrub and forest would deplete large amounts of soil moisture, and cause the occurrence of dried soil layer. This research is expected to provide insight into the mutual relationships between vegetation types and soil moisture content, and serve as guidance for vegetation restoration in the Loess Plateau.

Materials and Methods

Study Area

The study was conducted at the Zhifanggou Watershed of Ansai county, located in Shaanxi Province, China. Its geographical coordinates are 109°16'E and 36°46'N and with elevations ranging from 1100 to 1431m. The study site is characterized by a semi-arid climate, with a mean annual temperature of 8.8°C and an average frost-free period of 203 days. The average annual precipitation is 510 mm, of which more than 60% falls between July and September. The annual potential evaporation ranges from 1500 mm to 1800 mm. The soil is mainly Huangmian soil (Calcaric Cambisols, FAO), which develops from loess (wind-deposited sediment) parent material. The soil texture is 64% sand, 24% silt, and 12% clay (Zhang et al., 2011). The Loess Plateau is known for its deep soil layers, with the minimum subsoil depth being more than 10 m (Wang, Liu, & Xu, 2009a).

A substantial amount of land resources were reclaimed for cropland development given the considerable pressure arising from the demands of the expanding population prior to the 1950s in the watershed. The severe soil erosion and environmental problems caused by the irrational use of land resources contributed to the heavy financial losses incurred by the local communities. Soil water conservation and vegetation restoration have been carried out in the small watershed since the 1970s. The Chinese government also implemented the Grain for Green project in 1999, and converted cropland with slopes greater than 15° into grassland and woodland (Fu et al., 2009a; Fu et al., 2009b). Currently, the main land use types in the watershed are cropland, woodland (*Robinia pseudoacacia* L.), shrubland (*Caragana korshinskii* Kom.; *Hippophae rhamnoides* L.), artificial grassland (*Medicago sativa* L.), and natural grassland.

Experimental Design and Soil Moisture Sampling

Experimental Design

Seven typical land uses were selected for the measurement of soil moisture content. These land uses are located in the same area and all used to be croplands, with similar slopes, slope aspects, and elevations. During the past 30 years, they have been converted to seven different land uses: two croplands (*Setaria italica* (L.) P. Beauv and *Zea mays* L.), two shrublands (*C. korshinskii* and *H. rhamnoides*), one forest (*R. pseudoacacia*), one grassland (*M. sativa*), and one abandoned cropland for natural recovery. The shrublands and forest were established in the 1980s. *S. italica* and *Z. mays* were grown on terraces and dams, respectively. In the terraces, slopy land was constructed as stairs and the crops were cultivated on a narrow space, and the dams are usually built on the narrow part between two mountains to intercept the water and sediment flowing from slopy lands. The *S. italica* was seeded in late April, with a row spacing of 30 cm, and harvested in mid-October. The *M. sativa* was seeded in April 2002, with a density of 12 plants/m^2. The predominant species in the abandoned cropland for natural recovery is *Artemisia vestita* Wall. ex Bess. All the vegetation types have spread under the semi-arid conditions, even without irrigation. The description of the sample plots is presented in Table 1.

Soil Moisture Sampling

From 2004 to 2010, soil moisture was measured twice a year (i.e., in late April and late October) using a soil drill (4 cm core). Seven experimental plots were located on the seven land uses with a dimension of 10 m × 10 m. In each plot, three points were randomly selected to represent the soil moisture of this land use. Soil was sampled on sunny days at least 7 days after the latest precipitation to minimize the effect of antecedent precipitation on soil moisture. The measurements were extended to a depth of 300 cm in the cropland and up to 600 cm in the woodland, shrubland, and grassland. The soil samples were collected at intervals of 10 cm above and 20 cm below the 100 cm level. The collected soil samples were double bagged to prevent moisture loss, and immediately taken to the laboratory to measure gravimetric soil moisture content by the hot air drying method. The soil bulk densities of the seven land uses at the 0 cm to 100 cm profile were separately measured in 2011 (Table 2). For calculating the soil moisture storage below the 100 cm profile for each specific land use, the same soil bulk density as that used in the 80 cm to 100 cm profile was employed.

Table 1. Description of the sampling plots

Vegetation Type	Dominant Species	Slope Aspect	Slope (°)	Altitude (m)	Coverage (%)	Minor Herbaceous Coverage (%)
Cropland	*Setaria italica*	—	0	1310	40	None
	Zea mays	—	0	1200	54	None
Shrubland	*Hippophae rhamnoides*	E15°	23	1213	70	*A. vestita, Taraxacum duplex, Heteropappus altaicus* (15)
	Caragana korshinskii	W	23	1292	65	*A. capillaris, A. argyi, Lespedeza daurica* (40)
Grassland	*Medicago sativa*	N30°W	25	1280	60	None
Abandoned cropland for natural recovery	*Artemisia vestita*	—	0	1296	50	*A. leucophylla* and *Stipa bungeana* (10)
Woodland	*Robinia pseudoacacia*	W30°N	20	1265	55	*A. vestita, T. duplex, H. altaicus* (50)

Note: S. italica and *Z. mays* were grown on terraces and dams, respectively.

Table 2. Soil bulk density (g/cm^3) in the 0 to 100 cm depth in the seven land uses (n=3)

Soil Depth (cm)	*S. italica*	*Z. mays*	*H. rhamnoides*	*C. korshinskii*	*M. sativa*	*A. vestita*	*R. pseudoacacia*
0–10	1.15±0.04	1.37±0.03	1.29±0.03	1.26±0.01	1.12±0.01	1.32±0.03	1.22±0.03
10–20	1.46±0.01	1.39±0.00	1.39±0.02	1.28±0.03	1.21±0.01	1.33±0.02	1.29±0.04
20–40	1.41±0.04	1.46±0.01	1.46±0.04	1.29±0.00	1.30±0.02	1.36±0.03	1.31±0.01
40–60	1.31±0.00	1.48±0.02	1.46±0.02	1.35±0.01	1.22±0.03	1.45±0.03	1.33±0.04
60–80	1.33±0.01	1.38±0.01	1.47±0.05	1.34±0.01	1.24±0.00	1.37±0.03	1.28±0.04
80–100	1.28±0.00	1.42±0.01	1.28±0.04	1.28±0.01	1.29±0.02	1.33±0.02	1.25±0.07

Calculation of Variables and Statistical Analysis

Soil moisture storage is defined as the soil moisture content at a certain soil depth, and is expressed in units of water depth (mm) (Meng and Xia, 2004). Soil moisture storage is calculated from soil moisture content, soil bulk density, and soil depth as follows:

$$W_i = M_i \times D_i \times h \quad (i = 1,2,3.\ldots.n) \tag{1}$$

where W_i is the soil moisture storage at a certain soil depth (mm), M_i is the gravimetric soil moisture content (%) at such soil depth, D_i is the soil bulk density (g/cm^3) at such soil depth, h is the soil depth (mm), i is the soil sequence, and n is the number of measured layers.

The soil moisture storage in mid-to-late April of a given year is defined as the initial moisture storage (W_1), and the soil moisture storage in late October to early November is defined as the final soil moisture storage (W_2). Therefore, the variation in soil moisture storage in a year is:

$$\Delta W = W_2 - W_1 \tag{2}$$

For a more precise calculation of rainfall recharge depth, variance is used to determine whether soil moisture is recharged at a certain depth. The equation is as follows:

$$\delta = \frac{1}{n-1}\sum_{j}^{7}(x_{ij} - \overline{x}_i)^2, \quad j = 1,2\ldots.7 \tag{3}$$

where δ denotes the variance, x_{ij} represents the soil moisture at depth i of the jth year, and x_i is the average moisture at depth i from 2004 to 2010. For croplands, i=20. For the other five land uses, i=35. The variance was set to 1 and considered as a critical value. When the variance of soil moisture is greater than 1, the soil layer is considered a changeable layer. Otherwise, the layer is regarded as stable.

The concept of relative soil moisture (RSM) is used to describe the soil moisture levels at different soil depths under the seven land uses. RSM represents the percentage of soil moisture that accounts for the moisture storage capacity of each land use.

$$\mathrm{RSM} = M_i / \theta \times 100\% \tag{4}$$

where M_i represents the gravimetric soil moisture content (%), and θ represents the soil moisture storage capacity. In the present study, the soil moisture storage capacity was 20% (Yang & Shao, 2000), as the soil type was loess soil in the seven land uses and they have similar moisture storage capacity.

According to this definition, the soil moisture in the loess soil of the Loess Plateau is classified into four types (Yang & Shao, 2000): hardly available soil moisture (RSM < 30%), moderately available soil moisture (30% ≤ RSM ≤ 49%), easily available soil moisture (50% ≤ RSM ≤ 80%), and most easily available soil moisture (RSM > 80%).

SPSS 15.0 is used to obtain the descriptive characteristics of soil moisture and evaluate the differences in soil moisture among vegetation types.

Results

Dynamic Changes in Soil Moisture Under Different Land Uses

The dynamic changes in soil moisture storage capacity among different land uses at various soil layers are shown in Figures 1 and 2. The soil that constantly exhibited the highest soil moisture storage in the *Z. mays* cropland, followed by the *S. italica* cropland. By contrast, the *C. korshinskii* and *R. pseudoacacia* lands constantly exhibited

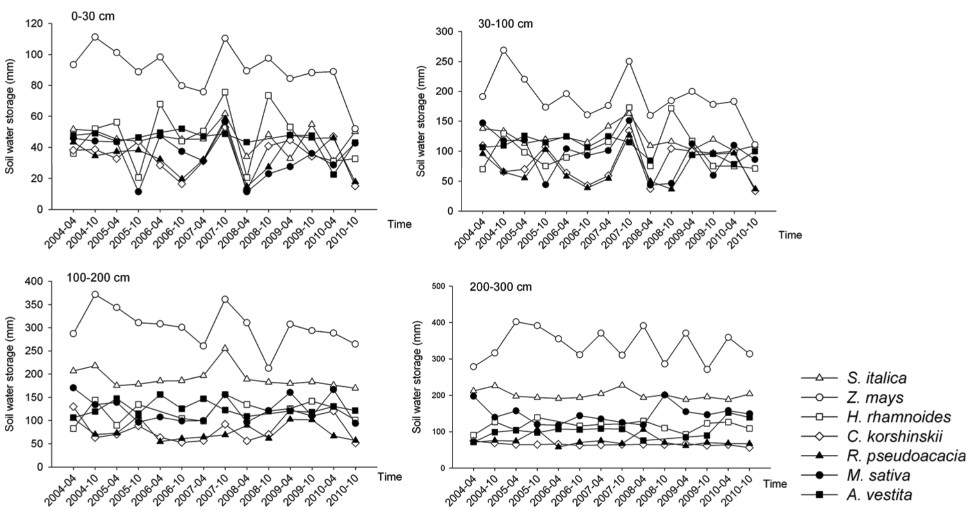

Figure 1. Dynamic changes in the soil moisture storage capacity of different land use patterns in the upper 300 cm profile from 2004 to 2010 at varied soil layers.

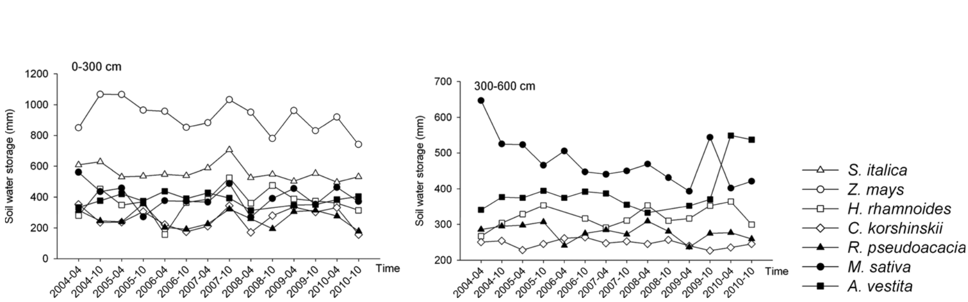

Figure 2. Dynamic changes in the soil moisture storage capacity of different land use patterns in the 0 to 300 cm depth and 300 to 600 cm depth from 2004 to 2010.

Table 3. Results (*P* value) of the multiple comparisons of soil moisture in the 0 to 200 cm depth under different land uses

	S. italica	*Z. mays*	*H. rhamnoides*	*C. korshinskii*	*M. sativa*	*A. vestita*	*R. pseudoacacia*
S. italica		0.000**	0.019*	0.000**	0.000**	0.001**	0.006**
Z. mays	0.000**		0.000**	0.000**	0.000**	0.000**	0.000**
H. rhamnoides	0.019*	0.000**		0.025*	0.015*	0.324^{ns}	0.658^{ns}
C. korshinskii	0.000**	0.000**	0.025*		0.821^{ns}	0.193^{ns}	0.068^{ns}
M. sativa	0.000**	0.000**	0.015*	0.821^{ns}		0.128^{ns}	0.041*
A. vestita	0.001**	0.000**	0.324^{ns}	0.193^{ns}	0.128^{ns}		0.584^{ns}
R. pseudoacacia	0.006**	0.000**	0.658^{ns}	0.068^{ns}	0.041*	0.584^{ns}	

Note: The values are replicates over time.
^{ns}, nonsignificant. $n = 7$.
$^{**}p < 0.01$. $^{*}p < 0.05$.

the lowest soil moisture storage, especially below the 100 cm profile. For all land uses, the soil moisture storage showed significant changes at the 0 cm to 30 cm and 30 cm to 100 cm profiles, indicating an obvious "replenishment–consumption–replenishment" process. However, the levels tended to remain constant below 100 cm throughout the study period. The differences in soil moisture storage under different vegetation types became more obvious with increasing soil depth. One-way ANOVA indicates that the soil moisture in the *S. italica* and *Z. mays* croplands was significantly higher than that in the other land uses. No significant difference in soil moisture was found among the *H. rhamnoides, C. korshinskii, M. sativa, A. vestita*, and *R. pseudoacacia* lands (Table 3).

Precipitation from April to October of 2004 to 2010 accounted for at least 86% of the annual rainfall during the study period (Table 4). Thus, using the difference in soil moisture storage in October and April to represent the inter-annual changes in soil moisture storage in an entire year is a reasonable approach. The inter-annual changes in the increase and decrease of soil moisture storage under different land uses are shown in Figure 3. The soil moisture storage at the 300 cm profile in the *S. italica*

Table 4. Precipitation during the study period

	Monthly Precipitation (mm)												Annual Precipitation (mm)
Year	1	2	3	4	5	6	7	8	9	10	11	12	
2004	0.0	0.0	0.0	10.5	20.8	65.9	133.1	164.9	41.3	3.5	2.8	3.5	446.3
2005	0.9	1.8	2.8	7.6	77.8	31.5	180.5	69.9	91.7	12.7	0.0	1.1	478.3
2006	13.7	4.3	0.0	6.3	77.7	51.2	119.4	66.0	63.2	10.2	15.8	1.8	429.6
2007	0.0	17.1	36.6	3.0	38.7	80.7	88.4	73.5	136.5	85.9	0.0	5.5	565.9
2008	30.5	5.2	15.6	18.3	5.6	72.8	51.8	65.6	111.3	11.2	0.0	0.0	387.9
2009	0.0	3.1	13.9	29.2	55.5	27.9	86.3	114.8	60.9	4.7	29.8	0.0	426.1
2010	0.0	11.9	3.9	53.7	33.8	31.9	52.7	178.4	45.0	12.3	0.0	0.0	423.6

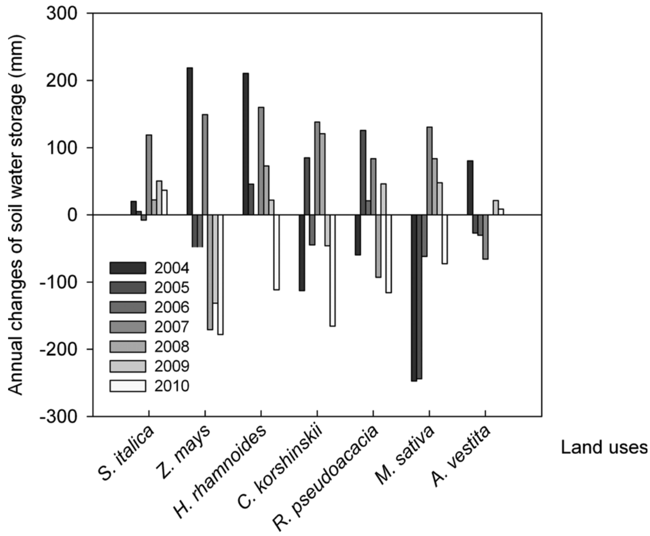

Figure 3. Inter-annual changes in soil moisture storage in the 0 to 300 cm depth of two croplands and in the 0 to 600 cm depth of the other five land uses from 2004 to 2010.

cropland consistently increased, except in 2006. The soil moisture storage in the *Z. mays* cropland increased only in 2004 and 2007. The soil moisture storage at the 600 cm profile in the *A. vestita* abandoned cropland showed slight changes during the study period. That in the *H. rhamnoides, C. korshinskii*, and *R. pseudoacacia* lands varied from an increase to a decrease. Significant losses in the soil moisture storage in the *M. sativa* grassland occurred between 2004 and 2006. The soil moisture storage in this land use increased between 2007 and 2009, and then dramatically decreased in 2010.

Soil Moisture Profile Distribution in Different Land Uses

Inter-Annual Changes in the Vertical Distribution of Soil Moisture

The vertical distribution of soil moisture across the *S. italica* and *A. vestita* lands were almost uniform during the study period, whereas that in the *Z. mays* cropland significantly changed in the entire 300 cm soil profile (Figure 4). For the remaining four land uses, the vertical distribution of soil moisture showed a similar pattern, that is, a large difference in soil moisture distribution was observed in the upper layer of the soil profile, and then the distribution converged at a depth of about 200 cm (Figure 5).

Rainfall Recharge Depth

The aforementioned results demonstrate that the moisture levels in the four land uses (*H. rhamnoides, C. korshinskii, M. sativa*, and *R. pseudoacacia*) varied at the 0 cm to 200 cm soil profile, but that the inter-annual levels were small below this depth. The precise depth at which soil moisture distribution converges depends primarily on annual precipitation and vegetation type. The depth from the surface to the convergence point can be referred to as the rainfall recharge depth because the soil moisture recharge would have reached its maximum by late October and would have exhibited constant level at this time of year (Yang & Yu, 1992).

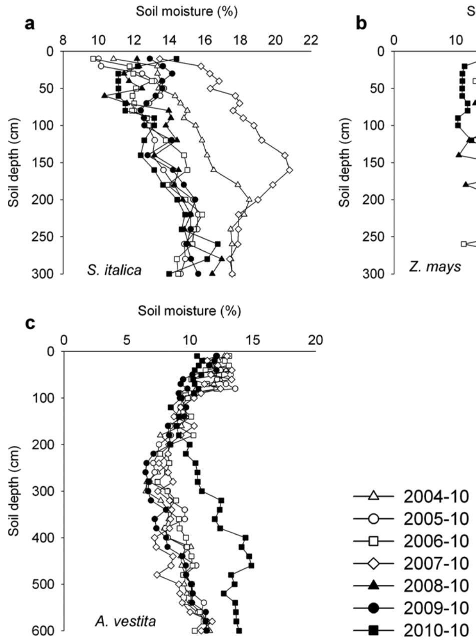

Figure 4. Vertical distribution of soil moisture in the 0 to 300 cm depth of two croplands and in the 0 to 600 cm depth of an abandoned cropland from 2004 to 2010.

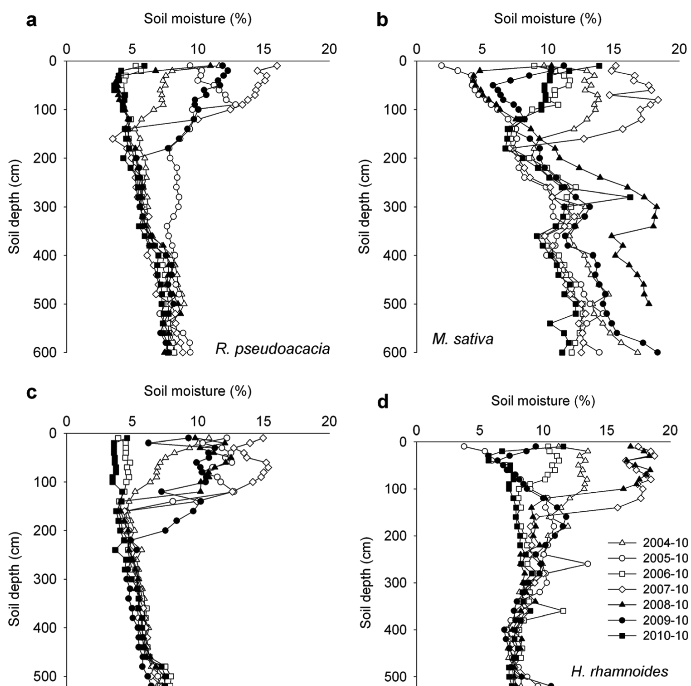

Figure 5. Vertical distribution of soil moisture in the 0 to 600 cm depth of two shrublands, a forestland, and a grassland from 2004 to 2010.

Figure 6 shows the variance in soil moisture in different years as a function of soil depth. The soil moisture in the entire 300 cm and 600 cm profiles in the two croplands and *M. sativa* land were recharged during the study period. The 0 cm to 200 cm profile was a stable layer for the *A. vestita* land, which experienced minimal recharging in the later months of 2004 to 2010. The maximum infiltration levels in the *H. rhamnoides* and *C. korshinskii* shrublands and *R. pseudoacacia* forestland were 200, 200, and 240 cm, respectively.

Soil Moisture Levels in Soil Profiles

Not all the water in soil can be used by vegetation. When soil moisture content is lower than the wilting coefficient, plants cannot absorb water from soil. When soil moisture is higher than field capacity, the excess water cannot be retained in soil. Therefore, only the soil moisture level that falls between the wilting point and field capacity can be used by plants.

From the aforementioned results, we realized that the soil moisture in almost complete 0–200 cm layer was rechargeable, while the soil moisture below 200 cm was almost stable. In this section, we tried to analyze the soil moisture status in the rechargeable layer and stable layer. On the basis of the classification of loess soil moisture levels, we categorized the soil moisture in the *Z. mays* cropland under the most easily available soil moisture category, and that in the *S. italica* cropland as belonging to or close to the most easily available soil moisture category at the 0 cm to 300 cm profile (Figure 7). The soil moisture at the 0 cm to 600 cm soil profile in the *A. vestita* land was maintained between the moderately and easily available soil moisture categories. The soil moisture

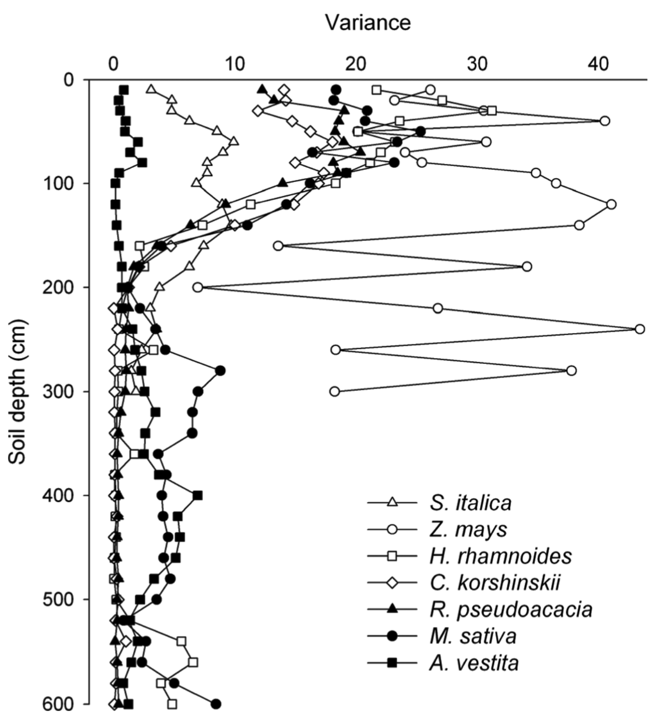

Figure 6. Variance in soil moisture in different years as a function of soil depth.

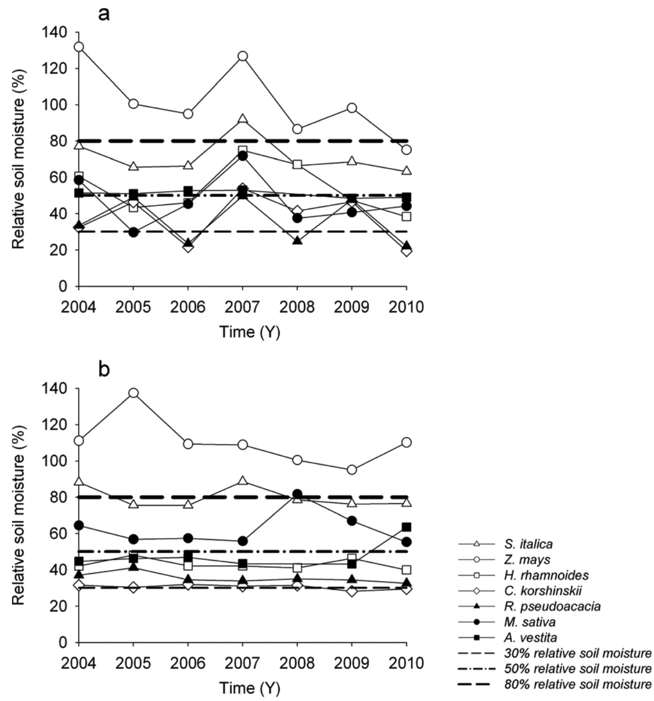

Figure 7. Relative soil moisture on the soil profiles in different land uses 2004 to 2010: (a) 0 to 200 cm depth; and (b) 200 to 300 cm depth in the croplands and 200 to 600 cm depth in the other land uses.

at the 0 cm to 200 cm profile in the *M. sativa, C. korshinskii*, and *R. pseudoacacia* lands was categorized as moderately available soil moisture. At the 200 cm to 600 cm profiles in the *C. korshinskii* and *R. pseudoacacia* lands were classified as close to hardly available soil moisture and that in the *M. sativa* land as easily available soil moisture. The soil moisture at the 0 cm to 200 cm profile in the *H. rhamnoides* land was classified as easily available soil moisture, and at the 200 cm to 600 cm profile was categorized as moderately available soil moisture.

Discussion

Soil Moisture Dynamics in Different Land Uses

Land use exerts fundamental effects on soil moisture storage capacity (Jiang et al., 2007) primarily because of the water consumption characteristics of vegetation and topography. In this study, the soil moisture storage at the 0 cm to 300 cm profile in the croplands was significantly higher than in the other land uses. This result agrees with the report of Wang, Liu, & Dang (2009b), who revealed that gentle slopes, terrace building, and lower crop water requirements result in higher soil moisture content in cropland. Zhang et al. (2006) reported that *C. korshinskii* and *R. pseudoacacia* consume large amounts of water, and that their root distribution can extend to 500 cm or deeper. In the current work, the *C. korshinskii* and *R. pseudoacacia* lands consistently showed the lowest soil moisture capacity in various soil layers during the study period. Fu et al. (2000) reported that forestland, grassland, and slope farmland exhibit almost no difference in soil moisture content at the soil surface. However, the differences increase as depth increases. In the present study, the soil moisture storage capacities at the 0 cm to 30 cm profile were almost the same for all land uses, except for the *Z. mays* cropland. The differences became more evident with increasing soil depth. This phenomenon is attributed mainly to the sparse vegetation cover, shallower root distribution, and shorter vegetation growth period in cropland than in shrubland and forestland (Huang et al., 2006). Bellot et al. (1999) indicated that transpiration is the main cause of soil moisture depletion. *C. korshinskii* and *R. pseudoacacia* exhibit high transpiration (Yuan & Xu, 2004) and deep root distribution (Guo & Shao, 2006). Although the root densities in deep soil layers are low (Guo & Shao, 2006), deep roots are key to soil moisture absorption (Wan et al., 1993; Yoder et al., 1998). Thus, shrubs and forests with deep root distributions deplete the water in deep soil.

An understanding of water balance is necessary in appreciating the role of various land uses in minimizing water loss and maximizing water utilization, eliminating the factors that limit crop production, and promoting vegetation restoration in semi-arid areas. Jiang et al. (2007) reported that soil moisture can maintain balance in natural grassland. In the present study, the soil moisture content in the *A. vestita* land changed only minimally, although the annual precipitation significantly varied during the seven-year period. This result is attributed mainly to the fact that the grass community considerably spread, enabling the species to successfully adapt to the local weather. Zhang et al. (2009) reported that precipitation exerts a positive compensation effect on soil moisture storage in terraced land—a finding consistent with our results. The *S. italica* land showed an increase in soil moisture during the study period, whereas the *Z. mays* land exhibited a decrease. These results are ascribed primarily to higher water consumption of *Z. mays* (Su et al., 1996) and less precipitation during the study period. *M. sativa* showed high water consumption in the entire soil profile (Wu & Liu, 2009; Cheng & Liu, 2011). Thus, the soil moisture storage in 2004 to 2006 decreased. Precipitation imposed a crucial effect on the *M. sativa* land (Zhao et al., 2005), thereby resulting in increased soil moisture storage after the wet year in 2007. Thereafter, soil moisture was depleted by *M. sativa*. In our study, the soil moisture balance in the shrublands and forestland varied from an increase to a decrease, that is, soil moisture content decreased annually. This result is in accordance with that obtained by Cheng et al. (2003), who reported that the dried out soil layers in *H. rhamnoides* lands exhibit annual improvement. From the perspective of soil moisture storage, natural grassland is the best land use for vegetation restoration in the semi-arid region of the Loess Plateau.

Soil Moisture Distribution in Different Land Uses

The vertical distribution of soil moisture differs by vegetation type. Vegetations mainly absorb water through root systems, so the depth of root distribution caused the different vertical soil moisture distribution in different land uses. The forest and shrub have much deeper root distribution than the crop (Zhang et al., 2002; Li et al., 2004; Guo & Shao, 2006; Sun et al., 2008); therefore, the soil-moisture content in the forest and shrub was much lower than the cropland in the deeper soil layers. But, the soil water dynamics was not only controlled by depth of root penetration, it was also related to the period of vegetation reproduction, root biomass, aboveground biomass and transpiration. Usually, shrub, forest, and some grass all have deep root distribution. However, in the present study, the *C. korshinskii* and *R. pseudoacacia* had higher aboveground biomass and transpiration than *M. sativa* and *H. rhamnoides*; therefore, the soil moisture content in 200–600 cm was lowest among the seven land uses. Jiang et al. (2007) reported that the soil moisture content in land cultivated with millet was approximately 10% to 15% at 40 cm to 400 cm deep soil layers during the entire growing season. In the present study, the soil moisture in the *S. italica* cropland was mostly stable in the 0 cm to 300 cm profile during the seven growing seasons; the value slightly increased with soil depth. The higher soil moisture content at the top 40 cm soil profile is associated primarily with the construction of terraces, which effectively received rainfall and improved infiltration, thereby enhancing the soil moisture content in the 0 cm to 50 cm soil profile (Zhang et al., 2007). Wang et al. (2009c) reported that no significant inter-annual variations in soil moisture occurred at a depth of below 200 cm in natural grassland. In the present study, the soil moisture exhibited slight changes in the entire 600 cm soil profile. This finding is attributed mainly to the growth of *A. vestita* at the top of the mountain, which is flat; these conditions decreased runoff loss and increased water infiltration. The soil moisture in the *C. korshinskii* land was recharged in the 0 to 200 cm depth. This result agrees with that of Wang et al. (2009c), who found that the soil moisture distribution in the 0 to 1000 cm depth converged at 200 cm in the *C. korshinskii* land in the Loess Plateau. The *C. korshinskii* roots were distributed mostly at the top 150 cm (Guo & Shao, 2006), causing the rapid depletion of soil moisture in the 0 to 200 cm depth. Therefore, the soil moisture content at the 0 cm to 200 cm profile tended to decrease on an annual basis. Zhang et al. (2006) studied the soil moisture distribution lines in the 0 to 400 cm depth in *R. pseudoacacia* land and found that the soil moisture below 50 cm was almost 8%. In the present study, the soil moisture was much lower, especially in the 0 cm to 200 cm profile; this value even decreased to 4%, indicating that soil moisture gradually decreased and drought stress intensified with the growth of *R. pseudoacacia*. Cheng et al. (2003) studied the soil moisture distribution in land with differently aged *H. rhamnoides* at the 0 cm to 500 cm profile and found that soil moisture increased with depth at 200 cm to 500 cm. In the current research, the soil moisture was almost stable below 200 cm, indicating that the growth of *H. rhamnoides* depleted soil moisture in deep soil layers.

Soil moisture availability refers to the capacity of soil to retain water that plants can consume. Theoretically, only the soil moisture content that falls between the wilting point and field capacity can be used by vegetation. Wang et al. (2009c) reported that soil moisture availability in cropland is always equal to or higher than average available moisture. In the present work, the soil moisture in the croplands was always readily available to the plants at the end of rainy seasons during the study period. The soil moisture levels at the 200 cm to 600 cm profile in the *C. korshinskii* and *R. pseudoacacia* lands were categorized as belonging or close to the hardly available soil moisture category, indicating that soil moisture was depleted by vegetation. Although the soil moisture at the 0 cm to 200 cm-depth profile was recharged, it was soon depleted by vegetation. Thus, obtaining available soil moisture every other year is difficult. The results indicate that soil moisture has reached the wilting point in the deep soil layers of mature shrub and forest, preventing vegetation from obtaining water from soil. As previously stated, vegetation in the Loess Plateau can obtain water only from precipitation. Thus, successive dry periods will lead to the widespread death of mature shrubs and forests (Wang et al., 2002; He et al., 2003).

Soil moisture should be considered for planning land use in the semi-arid Loess Plateau. Previous studies usually evaluated the soil moisture under different land uses at a certain time. But, as we all know, the Loess Plateau is known for its deep soil layer and precipitation is the only source of soil water. Whereas the precipitation has great annual variation between different years, the vegetation has different water consumption characteristics during different growth period. As a result, the measurement of soil moisture under different land uses for a long term is very important for accurately evaluating certain ecological restoration pattern. The present study investigated seven-year soil moisture dynamics and vertical distribution under seven land use patterns, and the results should serve as guidance for the vegetation construction in the Loess Plateau. However, different vegetations have different growth period and soil moisture consumption characteristics and, therefore, understanding the growth years and soil moisture consumption of different species in the soil moisture research would be useful for planning land use in the Loess Plateau.

Conclusion

This study investigated the soil moisture at the 0 cm to 300 cm soil profile in the *S. italica* and *Z. mays* croplands, as well as the soil moisture at the 0 cm to 600 cm soil profiles in the *H. rhamnoides, C. korshinskii, R. pseudoacacia, M. sativa*, and *A. vestita* lands, in the semi-arid area of the Loess Plateau for the period 2004 to 2010. The soil moisture storage at the 0 cm to 300 cm soil profile in the croplands was significantly higher than that in the other land uses. The same in the *S. italica* land increased during the seven-year period. The *A. vestita* land exhibited soil moisture balance during the study period. The *C. korshinskii* shrubland and *R. pseudoacacia* forest depleted soil moisture below the 200 cm profile, indicating close to hardly available moisture level category with little inter-annual changes. The soil moisture has reached the wilting point in the deep soil layers of mature shrubs and forests—an occurrence that prevents vegetation from obtaining water from soil. To resolve this problem, this study recommends the construction of terraces on gentle slopes and the conversion of farmland to grassland as the best options for the rehabilitation of the Loess Plateau.

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