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# Temporal stability of soil water storage under four types of revegetation on the northern Loess Plateau of China

Yu-Hua Jia[a,c,d], Ming-An Shao[b,*]

[a] Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling 712100, Shaanxi, China
[b] Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, China
[c] Shenyang Agricultural University, Shenyang 110866, Liaoning, China
[d] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

Conservation of soil water and restoration of vegetation have long been major subjects of concern on the northern Loess Plateau. Revegetation with species such as Korshinsk peashrub (KOP) and purple alfalfa (ALF), as well as with natural revegetation of fallow areas (NAF) have been used extensively. This paper examines the temporal stability of soil water storage (SWS) under these different revegetation types, including under millet (MIL) crops for comparison, grown in adjacent plots on a hillslope intending to provide information relevant to the strategic guidance of revegetation and soil water management practices. SWS was measured at 10-cm intervals in the soil profile to a depth of one meter using a neutron probe on 11 occasions between 2010 and 2011. The results indicated that: (1) time-averaged SWS relative to MIL decreased in the order of KOP (49.4 mm), ALF (32.4 mm) and NAF (14.9 mm) implying that shortages of soil water were induced largely by revegetation and were affected by the plant species. (2) Frequency distributions showed that points with probabilities of 0.5 were not stable between extreme soil water conditions; however, this result might be mitigated or avoided by increasing the sampling density and/or conducting measurement over a longer period. (3) Based on relative difference analysis, the most stable data points underestimated the mean SWS of the plots but were still valuable for precisely estimating the mean SWS of the experimental plot; in addition, among methods for estimating the plot average using representative points, directly using the value of relative difference or their standard deviation, or an index of temporal stability or the mean absolute bias error, no one method consistently performed better than another. (4) ALF presented the most temporally stable patterns among all types of revegetation tested, and vegetation cover and aboveground biomass were the main factors affecting SWS temporal stability. (5) Temporally stable points were located at the mid-slope of the plots. In conclusion, when temporal stability theory was applied to sloping lands mid-slope sampling is likely to give the best results but vegetation characteristics, and in particular vegetation cover should be highlighted.





## 1. Introduction

Soil water is a key variable directly controlling fluxes of water and energy at the soil surface. It not only influences the partitioning of precipitation into infiltration and runoff, but also affects the division of net radiation between sensible and latent heat (Martinez-Fernandez and Ceballos, 2003; Grayson and Western, 1998). In addition, soil water directly controls the availability of water to plants (Martinez-Fernandez and Ceballos, 2003; Grayson and Western, 1998) and constitutes the main source of water consumed by vegetation. Soil water is also involved in a variety of natural processes (hydrological, climatic, ecological, agricultural, etc.) that act at different spatio-temporal scales (Entin et al., 2000). Knowledge of soil water processes and its distribution is thus of importance to the efficient management of water resources, the successful conservation and restoration of vegetation and the sustainability of agricultural production.

The spatial heterogeneity of the factors affecting soil water, i.e. soil properties, topography, vegetation and climatic conditions, results in soil water also being spatially variable. However, for a spatial pattern of soil water within a given space and time, temporal stability is also widely observed. Furthermore, previously gathered empirical evidence indicates that temporal stability of soil water is widespread and pervasive (Guber et al., 2008).

The concept of temporal stability was first introduced by Vachaud et al. (1985) and is defined as the time-invariant association between spatial location and traditional statistical parametric

* Corresponding author. Tel.: +86 10 64889270; fax: +86 29 87012210.
*E-mail addresses:* jiayuhua@163.com (Y.-H. Jia), shaoma@igsnrr.ac.cn (M.-A. Shao).

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values. The temporal stability of soil water is a reflection of the temporal persistence of spatial structure (Schneider et al., 2008). From an agricultural point of view, the concept of temporal stability can help to prescribe a spatially variable but temporally stable irrigation water application pattern in precision farm management (Starr, 2005). If a field exhibits temporal stability in its soil water spatial pattern, selection of temporally stable sampling points offers an efficient alternative to the random sampling of many points (Jacobs et al., 2004), which in general is essential and corresponds to the spatially heterogeneous characteristics of the soil (Biswas and Si, 2011; Gao and Shao, 2012a). In hydrological modeling, such temporally stable points represent mean values that provide the basis for a correct definition of the antecedent mean soil water condition, which is critical in the simulation and prediction of soil water dynamics (Stephenson and Freeze, 1974). In addition, these representative points can help to verify process-based hydrological models with in situ data (Zhao et al., 2010). Moreover, a complete time series of soil water contents can be acquired if a predictive model is applied to a temporally stable point (Zhao et al., 2010; Zhou et al., 2007). These examples indicate that temporal stability has great potential for both practical and theoretical applications associated with water management.

Previous studies on temporal stability, conducted at multiple depths with different sampling themes, have varied considerably in terms of the area considered and duration. Soil properties, topography and vegetation can influence the temporal stability of soil-water patterns. A study conducted by Zhao et al. (2010) revealed that both vegetation and topography are less important than soil properties in controlling the temporal stability of soil water spatial patterns. However, the way in which vegetation affects or does not affect the temporal stability of soil water is still unclear. Gómez-Plaza et al. (2000) found that the spatial patterns of near-surface soil water observed at the transect scale in a semi-arid area of southeastern Spain became time stable when only topographical position or local topography were considered as factors that affected soil moisture, but they were less time stable when other factors, such as vegetation, were taken into account. In contrast, Biswas and Si (2011) found strong temporal stability at all scales and locations along a transect in the St. Denis National Wildlife Area of Canada when the effects of vegetative development were considered. Moreover, while the spatial patterns of soil water storage (SWS) were similar in the summer and fall seasons, they were clearly different in spring and fall, which directly resulted from the phenology of the vegetation. Seasonally varied vegetation, studied by Hupet and Vanclooster (2002) in a small maize field on a plateau in Belgium, played a non-negligible role in the temporal dynamics of the spatial patterns of soil water in the superficial layers. These studies illustrate that the role of vegetation in the study of temporal stability of soil water is important, and further relevant studies are required for reaching a consistent conclusion about the influence of vegetation.

Soil water is considered to be the most crucial factor for the growth of vegetation in semi-arid areas and has received much attention where restoration is needed. The northern Loess Plateau, situated on the borders between Shaanxi, Shanxi and Inner Mongolia in China, has undergone degradation of its vegetation and ecosystems due to intense soil erosion and human activities (Tang et al., 1993; Zhu and Shao, 2008). Since the 1950s, a series of government-backed projects, including extensive tree planting, check-dam building, watershed erosion control and the "Grain-for-Green" program, have been successively implemented to control soil erosion and restore vegetation (Chen et al., 2007). Accordingly, a variety of revegetation plant species or types have been used over a large area, though the stored soil water available for plants is often scarce (Hu et al., 2009). In addition, numerous studies in this region have focused on soil water. For example, Qiu et al. (2001) studied variations in the profiles and temporal dynamics of soil water; Fu et al. (2003) discussed the effects of land-use structure on the variability of soil water; Jun et al. (2010) evaluated the soil-water balance during vegetative restoration; and Huang et al. (2003) studied the effects of fertilizers applied to winter wheat on soil-water depletion and the decrease of soil water available to plants. Although many of these studies have centered on a variety of relevant subjects, few have focused on the temporal stability of soil water in this region (Hu et al., 2009, 2010a,b; Gao et al., 2011; Gao and Shao, 2012a,b), and even fewer studies have associated revegetation types with the temporal stability of soil water.

To address the issues mentioned above, we established four experimental plots differing in revegetation type and collected SWS data from depths within the upper 1-m soil layer for 11 months between 2010 and 2011. Our objectives were: (1) to gain insight into the temporal pattern of SWS for each revegetation type; (2) to find appropriate ways of representing the mean SWS for each experimental plot; and (3) to examine the effects of revegetation type on the temporal stability of SWS. The results have the potential to help improve the management of SWS, promote the efficiency of SWS measurements and guide revegetation practices.

## 2. Materials and methods

### 2.1. Description of study area

The study was carried out at the Liudaogou catchment (38°46′–38°51′N, 110°21′–110°23′E, 1094.0–1273.9 m elevation (Xiao et al., 2011)) in Shenmu county, on the northern Loess Plateau of China. The region is characterized by a temperate continental monsoon climate with a mean annual temperature of 8.4 °C and a mean annual precipitation of 437.4 mm. The precipitation is distributed unevenly among seasons; 70% falls from June to September. The mean annual wind speed is 2.5–2.7 m/s, and the maximum monthly wind speed is 9.7–14.4 m/s. The wind direction is mainly from the northwest from late autumn to early spring, but is mainly from the southeast in summer. The original vegetation has been destroyed by human activities. The region now has a semi-natural landscape, with restored grasslands and shrublands as integral parts (Jia et al., 2011).

### 2.2. Layout of experimental plots

Four primary revegetation types were selected: Korshinsk peashrub (*Caragana korshinskii Kom.*), purple alfalfa (*Medicago sativa*), natural fallow (NAF) and a grain crop of millet (MIL). Korshinsk peashrub (KOP) and purple alfalfa (ALF), which grow extensively in the region, are well adapted to environments with limited water and help to conserve soil and soil water by providing a dense cover during the growing season. Natural fallow occurs on abandoned cultivated fields and serves to recover natural vegetation. Millet, a traditional grain, was included as an example of a cultivated revegetation type.

In 2003, four adjacent experimental plots (61 m × 5 m), each containing one of the four revegetation types, were established on a uniform slope (12°–14°) with a northwestern aspect. The four plots had relatively intact surfaces and were located away from eroded gullies, so that the effects of topography were assumed to be identical. A concrete wall extending 0.2 m above the ground and 0.3 m into the ground was constructed around each plot. The concrete walls were 0.1 m wide and 0.8 m apart. The walls prevented the flow of surface and subsurface water from the adjacent plots and the surrounding fields (Fu et al., 2009). The length of the plot extended down the hillslope, and the order of the plots from left to right along the hillslope contour was KOP, ALF, NAF and MIL (Fig. 1). The

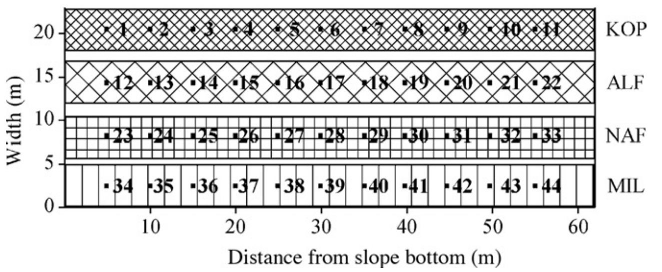


**Fig. 1.** Neutron probe tube positions and numbers in the plots under four revegetation types: Korshinsk peashrub (KOP); purple alfalfa (ALF); natural fallow (NAF); millet (MIL).

KOP plants were planted 70 cm apart, and ALF plants were planted 50 cm apart. Since 2004, no harvesting or fertilizing occurred in the KOP plot, but ALF was harvested by hand annually in late August. There was no human interference in the NAF plot after establishment and, in 2010, the dominant species were *Stipa bungeana*, *Artemisia capillaries*, *Astragalus sinicus* and *Lespedeza davurica*. All management practices in the MIL plot, including planting, fertilizing, harvesting and tilling, have been identical for the last seven years.

The soil is derived from aeolian loess deposits. Detailed data about vegetation characteristics and soil properties for each plot are shown in Table 1.

### 2.3. Measurements of soil water

In 2004, 11 neutron probe tubes, used for the measurement of soil water, were installed in a line in the middle of each plot running from the top to the bottom at intervals of five meters. The tube positions and numbering for each plot can be seen in Fig. 1.

Once a month from July to October in 2010, readings from a neutron probe (CNC503DR, China) were taken in each plot at every 10 cm to a depth of 1 m. In 2011, measurements were taken from April to October, which represented an entire growing season. Measurements were not taken between November 2010 and March 2011 based on the assumption that the variation in SWS would be negligible during this period due to the lack of vegetative activity and evapotranspiration would be minimal.

SWS within a depth of one meter was calculated from:

$$s = \theta_v \cdot h \cdot 10 \tag{1}$$

where $s$ is the SWS at a specific depth (mm), $\theta_v$ is the volumetric soil-water content at a specific depth ($cm^3\ cm^{-3}$) and $h$ is the soil-depth increment (10 cm). The 44 neutron tubes in the four plots measured on 11 occasions provided a total of 4840 observations of $\theta_v$ for determining SWS in this study.

**Table 1**
Vegetation characteristics and soil property in the experiment plots under four types of revegetation.

| Revegetation types | KOP | ALF | NAF | MIL |
|---|---|---|---|---|
| Aboveground biomass ($kg\ m^{-2}$) | 0.48 | 0.25 | 0.30 | 0.23 |
| Vegetation cover (%) | 0.70 | 0.40 | 0.50 | 0.30 |
| Plant organic carbon ($g\ kg^{-1}$) | 406.85 | 394.97 | 344.72 | 396.96 |
| Soil total phosphorus ($g\ kg^{-1}$) | 0.55 | 0.52 | 0.63 | 0.52 |
| Soil organic carbon ($g\ kg^{-1}$) | 2.09 | 1.55 | 1.84 | 1.66 |
| Profile bulk density ($g\ cm^{-3}$) | 1.51 | 1.57 | 1.34 | 1.59 |
| Sand (%) | 44.13 | 47.00 | 46.90 | 45.36 |
| Silt (%) | 42.56 | 42.40 | 41.86 | 42.97 |
| Clay (%) | 13.31 | 10.60 | 11.24 | 11.67 |

KOP, ALF, NAF and MIL stand for the revegetation types of Korshinsk peashrub, purple alfalfa, natural fallow and millet, respectively.

### 2.4. Statistical analysis

Relative difference analysis was used to evaluate the temporal stability of individual points in the experimental plots (Vachaud et al., 1985). Relative difference denotes the deviations between the independently observed values and the mean of those values (De Souza et al., 2011). Specifically, the relative difference ($\delta_{ij}$) is defined here as

$$\delta_{ij} = \frac{\Delta_{ij}}{\bar{S}_j} \tag{2}$$

where

$$\Delta_{ij} = S_{ij} - \bar{S}_{ij} \tag{3}$$

and

$$\bar{S}_j = \frac{1}{N}\sum_{i=1}^{N} S_{ij} \tag{4}$$

where $S_{ij}$ is SWS at observation point $i$ within the one-meter depth (mm) at time $j$ and $N$ is the number of observation points. The mean relative difference ($\bar{\delta}_i$) for each point is thus defined as

$$\bar{\delta}_i = \frac{1}{m}\sum_{j=1}^{m} \delta_{ij} \tag{5}$$

where $m$ identifies the time of observation. The standard deviation of the mean relative difference at each point, $\sigma(\delta_i)$, was calculated as an estimator of temporal stability:

$$\sigma(\delta_i) = \sum_{j=1}^{m} \left( \frac{(\delta_{ij} - \bar{\delta}_i)^2}{m-1} \right)^{1/2} \tag{6}$$

In order for the point to be considered as temporally stable, the mean SWS was required to satisfy two conditions: the mean relative difference should be close to zero and should have a minimal standard deviation.

Alternatively, two indices capturing the field mean were also considered. One was the index of time stability, $ITS_i$ (Zhao et al., 2010), which was based on the definition of Jacobs et al. (2004), and was calculated using a combination of $\bar{\delta}_i$ and $\sigma(\delta_i)$ from:

$$ITS_i = (\bar{\delta}_i^2 + \sigma(\delta_i)^2)^{1/2} \tag{7}$$

The other was the index of the mean absolute bias error, $\omega_i$ (Hu et al., 2010b), and was calculated by

$$\omega_i = \frac{1}{m}\sum_{j=1}^{m} \left| \frac{\delta_{ij} - \bar{\delta}_i}{1 + \bar{\delta}_i} \right| \tag{8}$$

By definition, the lowest values of $ITS_i$ or $\omega_i$ both corresponded to the points with the highest temporal stability. In order to gain a further understanding of the temporal stability, the nonparametric Spearman's correlation test, which indicates the degree of concordance of the spatial variability obtained at different times, was applied. The Spearman rank correlation coefficient, $r_s$, is defined by

$$r_s = 1 - \frac{6\sum_{j=1}^{n}(R_{ij} - R_{ij'})}{n(n^2 - 1)} \tag{9}$$

where $R_{ij}$ is the rank of the variable $S_{ij}$ observed at point $i$ at time $j$, $R_{ij'}$ is the rank of the same variable at the same point but at time $j'$, and $n$ is the number of observations. High values of $r_s$ between sampling dates indicated the temporal persistence of spatial patterns, i.e. the closer $r_s$ was to 1, the more stable the process (Vachaud et al., 1985).

Given that temporal stability of SWS could be associated with multiple factors covering vegetation characteristics and soil properties, we used a gray relational analysis (GRA) method to assess the effects of the investigated factors and to identify the primary factors that contributed to the temporal stability in the SWS spatial pattern. The GRA was based on the gray system theory initiated by Deng (1989), and has been verified to be an effective tool to solve the correlation extent of factors in a system with uncertain information (Fu et al., 2001; Lin and Lin, 2002; Tsai et al., 2003). The steps and calculations used by GRA are described as follows. Let the reference sequence be:

$$x_0 = (x_0(1), x_0(2), \ldots, x_0(k)). \tag{10}$$

Denoting the $q$ sequences to be compared as

$$x_i = (x_i(1), x_i(2), \ldots, x_i(k)), \quad i = 1, 2, \ldots, q. \tag{11}$$

Normalizing the sequences to ensure that all of them are in the same order. The normalized sequences can then be denoted as

$$x_i{}^* = (x_i(1)^*, x_i(2)^*, \ldots, x_i(k)^*) \tag{12}$$

The gray relational coefficient ($\xi_i(k)$) between the compared sequence, $x_i$, and the reference sequence, $x_0$, for the $j$th factor, was defined as

$$\xi_i(k) = \frac{\min_i \min_k |x_0(k) - x_i(k)| + \rho \max_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \rho \max_i \max_k |x_0(k) - x_i(k)|} \tag{13}$$

where $\rho$ is the distinguishing coefficient defined in the range of $0 \le \rho \le 1$, and typically $\rho = 0.5$. Then, the gray relational grade ($\varepsilon_i$) was derived from:

$$\varepsilon_i = \frac{1}{q} \sum_{i=1}^{q} \xi_i(k) \tag{14}$$

The relational grades, ranging between 0 and 1, quantitatively indicated the influence of factors being considered on the objective values. Accordingly, major factors corresponded to the higher values of $\varepsilon$, minor factors corresponded to the intermediate values, while negligible factors corresponded to the lower values.

## 3. Results and discussion

### 3.1. Temporal dynamics of SWS

The point-averaged values of SWS and the corresponding standard deviations for each revegetation type are shown in Fig. 2. SWS in the upper soil layers varied considerably between July 2010 and October 2011. The trends in the variation of SWS were largely similar for the four revegetation types.

As expected, SWS depended strongly on precipitation (Brocca et al., 2009). For example, in May 2011, SWS attained maximum values of 108.6 mm for KOP, 123.6 mm for ALF, 130.5 mm for NAF and 136.7 mm for MIL, four days after a rainstorm of 57.3 mm (Fig. 3). However, the single rainfall event of 19.5 mm occurring on September 2, 2011, may not have resulted alone in the third highest value of SWS 15 days later; frequent subsequent rainfalls and the approaching transition of autumn to winter may also have contributed to this high value. In contrast, a delayed measurement taken in late August 2010, recorded a low value of SWS after a rainfall of 64.7 mm in early August. Low values of SWS for all vegetation types usually coincided with periods of scattered or low rainfall. These results generally verified the strong dependency of SWS on precipitation.

During the entire experimental period, SWS fluctuated above or below a mean value (Fig. 2), which differed for the four revegetation types. The mean values were 73.1 mm, 88.1 mm, 105.6 mm and 120.5 mm for KOP, ALF, NAF and MIL, respectively. Thus, after revegetation, SWS values relative to the value of SWS under MIL were reduced by 49.4 mm, 32.4 mm and 14.9 mm for KOP, ALF and NAF, respectively. The decreases in SWS reflected the large differences in water consumption among the major plants in each revegetation type. KOP and ALF are both high water consumers that are perennial deep-rooted plants able to take up soil water from deeper soil layers. In contrast, NAF comprises natural herbaceous species, and MIL has fibrous roots distributed in the soil layers near the surface and they are both relatively low water consumers. The different revegetation types thus contributed to the different mean values of SWS. Relative to MIL, the reductions in SWS found under KOP (49.4 mm), ALF (32.4 mm) and NAF (14.9 mm), were mainly caused by the vegetation.

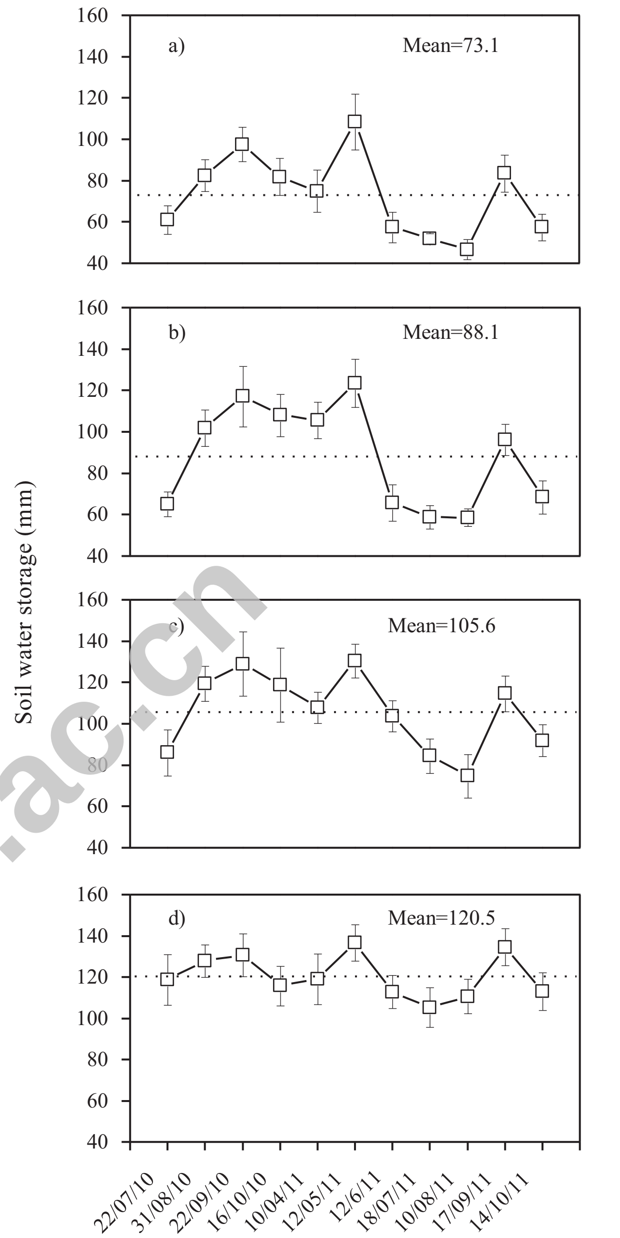


**Fig. 2.** Changes in soil water storage (SWS) over time in plots of: (a) Korshinsk peashrub; (b) purple alfalfa; (c) natural fallow and (d) millet. Vertical bars indicate one standard deviation for the 11 observation points in each plot. The dotted line represents the mean SWS during the study observation period.

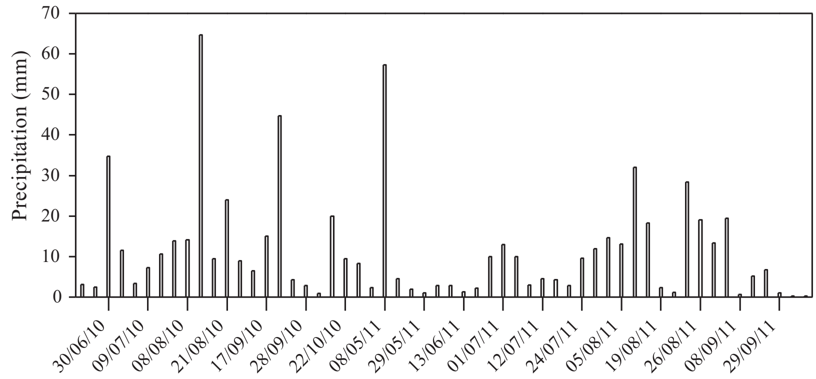


**Fig. 3.** Daily precipitation (mm) on the experimental plots.

### 3.2. Temporal stability of SWS

#### 3.2.1. Frequency distribution

The utility of an analysis of temporal stability depends on the reliability of a particular location to maintain its rank in the cumulative probability function at different sampling times (Brocca et al., 2009). Hence, frequency distribution is important in an analysis of temporal stability.

The maximum mean values of SWS for all the types of revegetation were attained on May 12, 2011 (Fig. 2). This date thus represented the time when the wettest conditions of the soil occurred. The minimum mean values of SWS for KOP, ALF and NAF were observed on September 17, 2011; however, the minimum mean value for MIL occurred earlier, on July 18, 2011. These two dates represented the time when the driest soil conditions occurred for the corresponding revegetation types. Normal distributions of the time-averaged values of SWS in each plot were confirmed. The cumulative probability functions for the dates, on which the two extreme conditions with the lowest and the highest mean values of SWS were recorded for each plot, are shown in Fig. 4. Points having a probability of 0.5 represented the mean of the experimental plots (Vachaud et al., 1985). However, such points in the present study did not maintain the same position under the two extreme conditions. Estimating the mean SWS of each plot from these points through frequency analysis thus proved unfeasible. This result was similar to that acquired by Brocca et al. (2009) for three experimental areas located in central Italy.

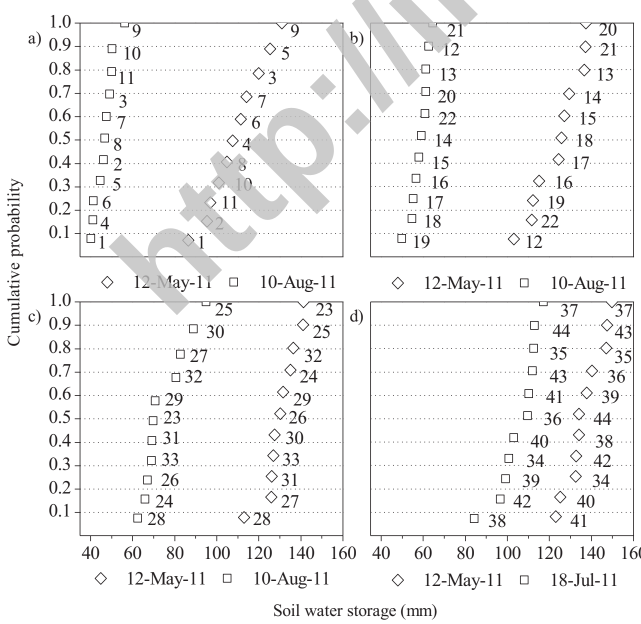


**Fig. 4.** Comparison of cumulative probability functions under the wettest and driest conditions for: (a) Korshinsk peashrub (KOP); (b) purple alfalfa (ALF); (c) natural fallow (NAF) and (d) millet (MIL). Data point labels refer to the observation points in the experimental plots.

Among the 11 observation points for any revegetation type, only two or three maintained the same rank under the two extreme conditions: points 1 and 9 for KOP; points 16 and 13 for ALF; points 28, 33 and 29 for NAL and points 35 and 37 for MIL. The other points moved up or down one or more positions in their rankings. Points appreciably changed position between wet and dry conditions. This behavior may be due to the highly specific circumstances of the soil profiles on the slope of the experimental plots, as Martinez-Fernandez and Ceballos (2003) have suggested. For example, the top-slope points in all plots except NAF, i.e. 11 for KOP, 22 for ALF and 44 for MIL, appeared to fall substantially in the rankings when soil conditions changed from the wettest to the driest, which may have been mainly due to the potentially more intense erosion induced by their top-slope positions and relatively good drainage. Points in the middle-slope of the NAF plot had relatively loose soil conditions, which could account for the large changes of position from shifts in extreme soil-water conditions.

In the study by Vachaud et al. (1985), most measurement points kept the same rank in extreme conditions. In comparison, Brocca et al. (2009) ascribed their dissimilar results to differences in sample depth. Vachaud et al. (1985) measured soil water stored in the upper (100 cm) soil layer, while Brocca et al. (2009) focused on the volumetric soil water in the surface (15 cm) layer. Martinez-Fernandez and Ceballos (2003) averaged soil-water content from depths of 5, 25, 50 and 100 cm of the soil profile, and Starks et al. (2006) took measurements at depths of 0–15, 15–30, 30–45 and 45–60 cm. The results in the latter two studies also differed from that of Vachaud et al. (1985). In view of these results, we infer that sample depth cannot completely explain the phenomenon that points with probability of 0.5 failed to represent the average plot, which may be avoided by a higher sampling density or a longer duration of experimentation to better represent extreme soil conditions.

#### 3.2.2. Relative difference analysis

Fig. 5 shows the ranked mean relative differences ($\bar{\delta}_i$) and the corresponding standard deviations ($\sigma(\delta_i)$) for all revegetation types. $\bar{\delta}_i$ indicates whether SWS of a particular sample point is more or less than the plot average (Bosch et al., 2006). Therefore, the points that systematically over- or underestimate the mean SWS can be identified. For KOP, ALF and MIL, six of the points are systematically below the zero relative-difference value, while five are above it. However, NAF differs in that five of the points

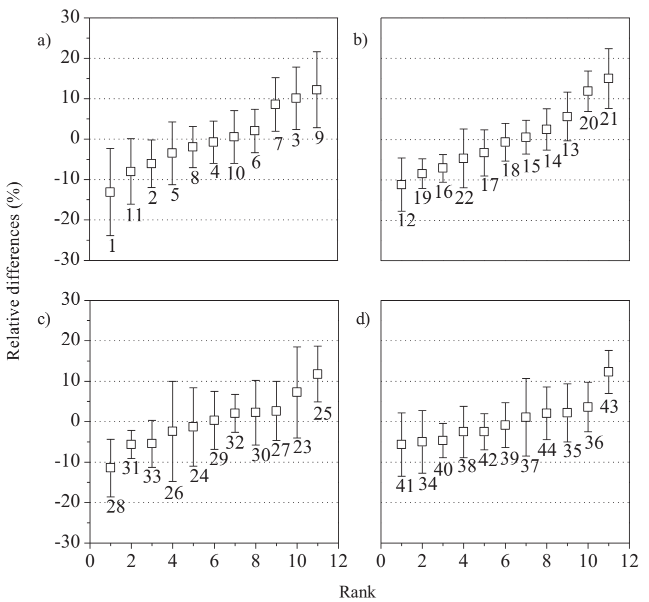


**Fig. 5.** Rank ordered mean relative differences with their standard deviations (vertical bars) for soil water storage in the four vegetation plots: (a) Korshinsk peashrub (KOP); (b) purple alfalfa (ALF); (c) natural fallow (NAF) and (d) millet (MIL). Data point labels refer to the observation points in the experimental plots.

are below the zero value, while six are above it. For all revegetation types, the most stable points (with the lowest $\sigma(\delta_i)$) are those that underestimate the mean SWS of the plots. These points are 8 ($\bar{\delta}_i = -1.9 \pm 5.1\%$), 16 ($\bar{\delta}_i = -7.1 \pm 3.4\%$), 31 ($\bar{\delta}_i = -5.6 \pm 3.5\%$) and 40 ($\bar{\delta}_i = -4.7 \pm 4.3\%$) for KOP, ALF, NAF and MIL, respectively. Furthermore, for ALF and MIL, points below the zero relative-difference value, compared with those above it, have slightly lower mean values of $\sigma(\delta_i)$ (5.2% vs. 5.6% for ALF, 6.0% vs. 7.1% for MIL). Temporal stability was thus higher at the points characterizing drier conditions. This conclusion is in agreement with those of Martínez-Fernández and Ceballos (2005) and Hu et al. (2010a). However, similar findings were not observed in the plots of KOP and NAF. For KOP, the mean values of $\sigma(\delta_i)$ for the points with $\bar{\delta}_i < 0$ and $\bar{\delta}_i > 0$ are the same (7.1%). For NAF, the mean values of $\sigma(\delta_i)$ for the points with $\bar{\delta}_i < 0$ and $\bar{\delta}_i > 0$ are 7.7% and 7.5%, respectively. These results suggest that points underestimating the plot-average SWS are less stable for KOP and NAF compared to ALF and MIL. The ability of the soil to retain water in the KOP and NAF plots varied more than in the ALF and MIL plots, owing to larger soil pore spaces and looser soils resulting from the extensive root systems of KOP and NAF.

The range of $\bar{\delta}_i$ varied distinctly for different revegetation types. The values were 25.3% (−13.1% to 12.2%) for KOP, 26.2% (−11.2% to 15.0%) for ALF, 23.2% (−11.5% to 11.7%) for NAF and 17.9% (−5.6% to 12.3%) for MIL. The $\bar{\delta}_i$ deviated less than 27% from the plot mean. In addition, $\sigma(\delta_i)$, with values less than 13%, exceeded $\bar{\delta}_i$ for most points in the plots. An individual measurement can thus deviate much more from the mean soil water of the plot than indicated by its value of $\bar{\delta}_i$ (Schneider et al., 2008). The range of $\bar{\delta}_i$ for MIL is lower than that of the others, perhaps because the consumption of water in crops differs greatly from that in non-crops during the growing season, and because the SWS for MIL was commonly higher than that of the other types of vegetation. Our values of $\bar{\delta}_i$ were lower than those in some other studies (e.g. Cosh et al., 2006; Schneider et al., 2008). Brocca et al. (2009) proposed that the spatial extent of the sampling campaigns and the depths of the measurements contributed to differences in the variability of $\bar{\delta}_i$ and $\sigma(\delta_i)$. Schneider et al. (2008) suggested that, given a similar spatial extent and sampling depth, the experimental layout might partly account for these differences. The plot area and sampling intervals along the transect in our study were comparatively small, which probably was the main reason for the lower values of $\bar{\delta}_i$.

In general, the points with $\bar{\delta}_i$ close to zero and minimal $\sigma(\delta_i)$ were identified as most suitably representing the mean SWS of the experimental plot. Points approaching the plot average were 10 ($\bar{\delta}_i = 0.5 \pm 6.5\%$), 15 ($\bar{\delta}_i = 0.5 \pm 4.2\%$), 29 ($\bar{\delta}_i = 0.4 \pm 7.2\%$) and 39 ($\bar{\delta}_i = -0.8 \pm 5.5\%$) for KOP, ALF, NAF and MIL, respectively. However, due to their lower stability, they might not appropriately represent the plot-average water storage. No points fulfilled these two requirements. In Hu et al. (2009), the site with $\bar{\delta}_i$ closest to zero and a low $\sigma(\delta_i)$ was considered as best representing the mean SWS of the entire watershed. More simply, Grayson and Western (1998) suggested that points where $\bar{\delta}_i$ approached zero could be used directly for estimating a region's mean SWS. It is also worth mentioning that Jacobs et al. (2004) and Zhao et al. (2010) proposed the index of time stability ($ITS_i$), and Hu et al. (2010b) put forward the index of the mean absolute bias error ($\omega_i$); using both indices might become necessary and supplementary for identification of the most suitable points representing the plot average. Based on these findings, the resuming of representative points identification was performed, with estimates obtained in four different ways: (i) from points with $\bar{\delta}_i$ closest to zero; (ii) from points with $\sigma(\delta_i)$, (iii and iv) from $ITS_i$ and $\omega_i$ reaching minimal values, respectively. To analyze how well these types of identified points represented the plot average for each revegetation type, linear regression analysis was conducted between the estimates, i.e. between the values of representative points and the measured means; the results are shown in Tables 2–5. The performance of an empirical relationship for estimates from points with a near-zero $\bar{\delta}_i$, as indicated by the $R^2$ values, was similar to that with a minimal $\sigma(\delta_i)$, since for both ALF and MIL plots, the former produced better predictions than the latter, while for KOP and NAF, the latter produced better predictions than the former. The SWS of points selected using criteria of $ITS_i$ or $\omega_i$ were well fitted with the plot average for each revegetation type, and some of them even explained more variation than those identified by the minimal $\sigma(\delta_i)$. Representative points determined by $ITS_i$ were completely different from those identified by minimal

**Table 2**
Regression equations and coefficients ($R^2$) derived from linear regression of measured SWS values ($x$) and estimates ($y$) from observation point numbers with MRD closest to zero.

| Revegetation types | Observation points with MRD closest to zero | Regression equations | Coefficients of determination |
|---|---|---|---|
| KOP | 10 | $y = 0.859x + 10.004$ | $R^2 = 0.948$ |
| ALF | 15 | $y = 1.054x - 3.913$ | $R^2 = 0.988$ |
| NAF | 29 | $y = 1.287x - 29.08$ | $R^2 = 0.957$ |
| MIL | 39 | $y = 1.255x - 32.02$ | $R^2 = 0.812$ |

SWS, soil water storage. MRD refers to the mean relative difference. KOP, ALF, NAF and MIL stand for the revegetation types of Korshinsk peashrub, purple alfalfa, natural fallow and millet, respectively.

**Table 3**
Regression equations and coefficients ($R^2$) derived from linear regression of measured SWS values ($x$) and estimates ($y$) directly from observation point numbers with minimal SDRD.

| Revegetation types | Observation points with minimal SDRD | Regression equations | Coefficients of determination |
|---|---|---|---|
| KOP | 8 | $y = 1.005x - 1.732$ | $R^2 = 0.963$ |
| ALF | 16 | $y = 0.946x - 1.406$ | $R^2 = 0.985$ |
| NAF | 31 | $y = 0.982x - 3.965$ | $R^2 = 0.964$ |
| MIL | 40 | $y = 0.897x + 6.307$ | $R^2 = 0.810$ |

SWS, soil water storage. SDRD refers to standard deviation of relative differences. KOP, ALF, NAF and MIL stand for the revegetation types of Korshinsk peashrub, purple alfalfa, natural fallow and millet, respectively.

**Table 4**
Regression equations and coefficients ($R^2$) derived from linear regression of measured SWS values ($x$) and estimates ($y$) from the observation point numbers with minimal values of index of time-stability.

| Revegetation types | Observation points with minimal SDRD | Regression equations | Coefficients of determination |
|---|---|---|---|
| KOP | 4 | $y = 1.054x - 4.127$ | $R^2 = 0.979$ |
| ALF | 15 | $y = 1.054x - 3.914$ | $R^2 = 0.988$ |
| NAF | 32 | $y = 0.948x + 7.347$ | $R^2 = 0.946$ |
| MIL | 42 | $y = 1.274x - 36.203$ | $R^2 = 0.885$ |

SWS, soil water storage. KOP, ALF, NAF and MIL stand for the revegetation types of Korshinsk peashrub, purple alfalfa, natural fallow and millet, respectively.

**Table 5**
Regression equations and coefficients ($R^2$) derived from linear regression of measured SWS values ($x$) and estimates ($y$) calculated from the observation point numbers with minimal values of mean absolute bias error.

| Revegetation types | Observation points with minimal SDRD | Regression equations | Coefficients of determination |
|---|---|---|---|
| KOP | 6 | $y = 1.121x - 6.872$ | $R^2 = 0.983$ |
| ALF | 20 | $y = 1.22x - 8.267$ | $R^2 = 0.979$ |
| NAF | 31 | $y = 0.982x - 3.965$ | $R^2 = 0.964$ |
| MIL | 40 | $y = 0.897x + 6.307$ | $R^2 = 0.810$ |

SWS, soil water storage. SDRD refers to standard deviation of relative difference. KOP, ALF, NAF and MIL stand for the revegetation types of Korshinsk peashrub, purple alfalfa, natural fallow and millet, respectively.

$\sigma(\delta_i)$, and prediction performances were better for points identified by minimal $ITS_i$ than those where minimal $\sigma(\delta_i)$ was used, with an exception being the NAF plot. When determined by $\omega_i$, two of the representative points were in agreement with those identified through minimal $\sigma(\delta_i)$, i.e. points 31 for NAF and 40 for MIL. Overall, the coefficients of determination, except for MIL, were all more than 0.94, which accounted for over 94% of the variability in the measured data. It was apparent that the prediction peformances directly using these four types of points for MIL were not as good as those for the other three plots.

Grayson and Western (1998) pointed out that temporally stable points with a non-zero $\bar{\delta}_i$ could be used to estimate the mean of the experimental plot ($\bar{s}$) if a constant offset $\bar{\delta}_i$ was included:

$$\bar{s} = \frac{s_i}{1 + \bar{\delta}_i} \tag{15}$$

where $s_i$ is the SWS of a temporally stable point with a non-zero $\bar{\delta}_i$. We applied the values of most stable points identified by minimal $\sigma(\delta_i)$ into this equation and obtained new estimates for each plot. Then linear regression analyses of the estimates and the measured plot means were performed. All the plots had relationships with good fits, especially for MIL with $R^2 = 0.943$ (Table 6). Thus, by introducing the $\bar{\delta}_i$, and its $s_i$, of the most stable point into Eq. (15), we can acquire the best estimate for the plot-averaged SWS for the four revegetation types. It should be stressed that a minimal $\sigma(\delta_i)$ is more important than a value of $\bar{\delta}_i$ close to zero because points with low standard deviations will give more precise estimates even though their values deviate from the mean SWS of the plot. These findings were also validated by the study of Schneider et al. (2008).

**Table 6**
Regression equations and coefficients ($R^2$) derived from linear regression of measured SWS values ($x$) and estimates ($y$) calculated through Eq. (15) for the observation point numbers with minimal SDRD.

| Revegetation types | Observation points with minimal SDRD | Regression equations | Coefficients of determination |
|---|---|---|---|
| KOP | 8 | $y = 0.996x + 0.379$ | $R^2 = 0.999$ |
| ALF | 16 | $y = 0.974x + 2.441$ | $R^2 = 0.994$ |
| NAF | 31 | $y = 0.956x + 4.695$ | $R^2 = 0.989$ |
| MIL | 40 | $y = 0.957x + 5.295$ | $R^2 = 0.943$ |

SWS, soil water storage. SDRD refers to standard deviation of relative difference. KOP, ALF, NAF and MIL stand for the revegetation types of Korshinsk peashrub, purple alfalfa, natural fallow and millet, respectively.

According to the aforementioned results, points 8, 4 and 6 in KOP, 16, 15 and 20 in ALF, 31 and 32 in NAF, 40 and 42 in MIL were all listed as the most stable points. With regard to the positions in the plots, we found that they were mainly on the middle or above middle slope. Therefore, they represented to some extent the average topography characteristics of the slope, which in turn strengthened their representativeness and ability to be the field mean. Similarly, Grayson and Western (1998) reported that the CASMM (catchment average soil moisture monitoring) sites in Tarrawarra catchment tended to be near the mid-slopes. This finding was especially useful in finding a reliable location that represented an area's mean water content in a sloping field.

### 3.2.3. Spearman rank correlation coefficient

A non-parametric Spearman's test of rank correlation coefficient, $r_s$, determined the persistence of the spatial pattern of SWS between the campaigns of measurement conducted in different months. Table 7 gives the computed Spearman correlation coefficients for the four revegetation types. By averaging the value of $r_s$ for each revegetation type and then ordering $\bar{r}_s$ from large to small, the rankings were: 0.66 for ALF, 0.51 for KOP, 0.43 for NAF and 0.34 for MIL. Additionally, the majority of $r_s$ for ALF were significant at $P < 0.05$, while fewer than half of $r_s$ for the other types were significant. These results indicated that the temporal stability of the distribution pattern of SWS for ALF was the highest and the loss of information between two measurements was the smallest, according to the findings of Gómez-Plaza et al. (2000). Nearly all $r_s$ in the data sets of many studies have been significant at $P < 0.05$ or $P < 0.001$ (Brocca et al., 2009; Coppola et al., 2011; Starks et al., 2006; Vachaud et al., 1985). However, no strong temporal stability was observed in the present study. Temporal stability was generally high for ALF, low for NAF, and lowest for MIL while for KOP it was intermediate. When the effects of topography, climate and soil texture on temporal persistence at the plot scale were all excluded, the discrepancies among the revegetation types was assumed to mainly account for the pronounced differences in the magnitude of $\bar{r}_s$ among plots.

Due to the weaker temporal stability for the KOP, NAF and MIL plots, further analyses of the $r_s$ matrix were only performed for the ALF plot. During the first five months of measurements in 2011, the rank correlation $r_s$ for ALF decreased when the time interval between two observations was long. This relationship suggested that the pattern of SWS persisted for a certain time and was susceptible to intervals of time. Schneider et al. (2008) ascribed similar results to the discharge of soil water in a semi-arid steppe in China. In addition, the date of August 10, 2011, in most cases, had a coefficient less than 0.45 when compared with the other dates. While the date of September 17, 2011 generally had coefficients greater than 0.65, when compared with any other date excluding August 10, 2011. These large differences in the magnitude of $r_s$ were primarily caused by the drying-recharge transition of the soil.

Hu et al. (2010a) concluded that land use did not affect the temporal stability of soil-water content when comparing the mean standard deviations of relative differences and the mean absolute bias errors between Bunge needlegrass and Korshinsk peashrub. However, multiple comparisons of $\sigma(\delta_i)$ after analyses of variation ($P < 0.05$) in our study (Table 8) indicated that the temporal stability for ALF was significantly higher than that of MIL, and no significant differences were found among KOP, NAF and MIL. This result was consistent with that obtained by comparisons of $\bar{r}_s$.

**Table 7**
Matrix of Spearman correlation coefficients corresponding to SWS data measured on various dates for the different revegetation plots.

| | 22/07/10 | 31/08/10 | 22/09/10 | 16/10/10 | 10/04/11 | 12/05/11 | 12/6/11 | 18/07/11 | 10/08/11 | 17/09/11 | 14/10/11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **KOP** | | | | | | | | | | | |
| 22/07/10 | 1 | 0.56 | 0.64* | 0.79** | −0.10 | 0.67* | 0.83** | 0.45 | 0.60 | 0.72* | 0.82** |
| 31/08/10 | | 1 | 0.76** | 0.68* | 0.29 | 0.66* | 0.76** | 0.77** | 0.16 | 0.71* | 0.72* |
| 22/09/10 | | | 1 | 0.55 | 0.36 | 0.50 | 0.76** | 0.49 | 0.05 | 0.61* | 0.57 |
| 16/10/10 | | | | 1 | 0 | 0.61* | 0.86** | 0.66* | 0.68* | 0.72* | 0.82** |
| 10/04/11 | | | | | 1 | 0 | −0.06 | 0.39 | −0.53 | −0.28 | −0.26 |
| 12/05/11 | | | | | | 1 | 0.60 | 0.67* | 0.31 | 0.53 | 0.61* |
| 12/6/11 | | | | | | | 1 | 0.55 | 0.57 | 0.94** | 0.95** |
| 18/07/11 | | | | | | | | 1 | 0.19 | 0.45 | 0.54 |
| 10/08/11 | | | | | | | | | 1 | 0.56 | 0.64* |
| 17/09/11 | | | | | | | | | | 1 | 0.97** |
| 14/10/11 | | | | | | | | | | | 1 |
| **ALF** | | | | | | | | | | | |
| 22/07/10 | 1 | 0.37 | 0.56 | 0.57 | 0.72* | 0.67* | 0.81** | 0.70* | 0.36 | 0.78** | 0.67* |
| 31/08/10 | | 1 | 0.91** | 0.93** | 0.80** | 0.89** | 0.52 | 0.56 | 0.15 | 0.66* | 0.78** |
| 22/09/10 | | | 1 | 0.90** | 0.89** | 0.86** | 0.55 | 0.56 | 0.14 | 0.70* | 0.74** |
| 16/10/10 | | | | 1 | 0.88** | 0.96** | 0.60 | 0.56 | 0.30 | 0.79** | 0.79** |
| 10/04/11 | | | | | 1 | 0.90** | 0.62* | 0.53 | 0.29 | 0.82** | 0.76** |
| 12/05/11 | | | | | | 1 | 0.74** | 0.68* | 0.33 | 0.88** | 0.89** |
| 12/6/11 | | | | | | | 1 | 0.83** | 0.45 | 0.65* | 0.92** |
| 18/07/11 | | | | | | | | 1 | 0.44 | 0.70* | 0.82** |
| 10/08/11 | | | | | | | | | 1 | 0.29 | 0.41 |
| 17/09/11 | | | | | | | | | | 1 | 0.73* |
| 14/10/11 | | | | | | | | | | | 1 |
| **NAF** | | | | | | | | | | | |
| 22/07/10 | 1 | 0.26 | −0.18 | −0.23 | −0.21 | −0.10 | 0.02 | 0.36 | 0.36 | −0.17 | −0.16 |
| 31/08/10 | | 1 | 0.77** | 0.70* | 0.68* | 0.57 | 0.88** | 0.42 | 0.79** | 0.52 | 0.39 |
| 22/09/10 | | | 1 | 0.74** | 0.81** | 0.74** | 0.65* | 0.21 | 0.74** | 0.73* | 0.54 |
| 16/10/10 | | | | 1 | 0.93** | 0.64* | 0.80** | 0.15 | 0.41 | 0.42 | 0.46 |
| 10/04/11 | | | | | 1 | 0.82** | 0.75** | 0.06 | 0.45 | 0.51 | 0.56 |
| 12/05/11 | | | | | | 1 | 0.61* | −0.16 | 0.32 | 0.69* | 0.74** |
| 12/6/11 | | | | | | | 1 | 0.08 | 0.46 | 0.50 | 0.52 |
| 18/07/11 | | | | | | | | 1 | 0.69* | −0.05 | −0.29 |
| 10/08/11 | | | | | | | | | 1 | 0.46 | 0.18 |
| 17/09/11 | | | | | | | | | | 1 | 0.89** |
| 14/10/11 | | | | | | | | | | | 1 |
| **MIL** | | | | | | | | | | | |
| 22/07/10 | 1 | 0.26 | −0.09 | 0.03 | 0.46 | 0.66* | 0.21 | 0.1 | 0.42 | 0.36 | 0.82** |
| 31/08/10 | | 1 | 0.11 | 0.32 | 0.05 | 0.39 | 0.21 | 0.05 | 0.17 | 0.26 | 0.07 |
| 22/09/10 | | | 1 | 0.17 | 0.42 | 0.33 | 0.08 | 0.32 | 0.19 | 0.37 | 0.23 |
| 16/10/10 | | | | 1 | 0.44 | 0.29 | −0.15 | −0.12 | 0.37 | 0.55 | 0.36 |
| 10/04/11 | | | | | 1 | 0.58 | −0.02 | 0.14 | 0.67* | 0.51 | 0.72* |
| 12/05/11 | | | | | | 1 | 0.35 | 0.52 | 0.66* | 0.81** | 0.78** |
| 12/6/11 | | | | | | | 1 | 0.68** | 0.27 | 0 | 0.25 |
| 18/07/11 | | | | | | | | 1 | 0.63 | 0.34 | 0.36 |
| 10/08/11 | | | | | | | | | 1 | 0.47 | 0.69* |
| 17/09/11 | | | | | | | | | | 1 | 0.65* |
| 14/10/11 | | | | | | | | | | | 1 |

SWS, soil water storage. KOP, ALF, NAF and MIL stand for the revegetation types of Korshinsk peashrub, purple alfalfa, natural fallow and millet, respectively.
* Significance level less than 0.05.
** Significance level less than 0.01.

**Table 8**
Multiple comparisons (Tukey HSD) of mean SDRD after variation analysis.

| Revegetation types | Sample number | Average SDRD after arcsine square root transformation | Tukey HSD |
|---|---|---|---|
| NAF | 121 | 0.2757 | a |
| KOP | 121 | 0.2684 | ab |
| MIL | 121 | 0.2463 | ab |
| ALF | 121 | 0.2320 | b |

HSD is the abbreviation of honestly significant difference. SDRD refers to standard deviation of relative difference. KOP, ALF, NAF and MIL stand for the revegetation types of Korshinsk peashrub, purple alfalfa, natural fallow and millet, respectively. Different lower-case letters within columns is significantly different at $P < 0.05$.

### 3.2.4. Determination of primary factors

According to the above-mentioned results, the temporal stability of the SWS spatial pattern changed with the revegetation types. However, it was not clear which specific factors could accurately interpret the difference in temporal stability that occurred among the four vegetated plots. The summary of the investigation results of the various factors in the corresponding plots (Table 1) suggested that a definite conclusion could not be directly attained from the information implied by the data, which was a collection of different factors. In this case, gray relational analysis (GRA) afforded an effective means to achieve this objective. Values of mean $\sigma(\delta_i)$, after an arcsine square root transformation, were assigned to be the reference sequence (Table 8). Factors to be considered included aboveground biomass, vegetation cover, plant organic carbon, soil total P, soil organic carbon, profile bulk density, particle size including the percentage of sand, silt and clay, as well as mean SWS (Table 1 and Fig. 2). The gray relational grades for all the investigated factors are presented in Table 9.

In GRA a relational grade close to 1 means that the positive correlative extent of the factor to temporal stability is great. In

**Table 9**
Gray relational grade of all investigated factors in the analysis of soil water storage temporal stability.

| Factors | Gray relational grade | Rank |
|---|---|---|
| Vegetation cover | 0.745 | 1 |
| Aboveground biomass | 0.710 | 2 |
| Clay | 0.694 | 3 |
| Plant organic carbon | 0.668 | 4 |
| Soil organic carbon | 0.656 | 5 |
| Profile bulk density | 0.634 | 6 |
| Sand | 0.581 | 7 |
| Silt | 0.568 | 8 |
| Soil total phosphorus | 0.535 | 9 |
| Mean SWS | 0.467 | 10 |

SWS, soil water storage.

addition, the magnitude of the grade indicates the importance of the factors. Our results showed that both vegetation cover (0.745) and aboveground biomass (0.710) were the primary factors that most affected the temporal stability of SWS of the four vegetated plots (Table 9). Secondary factors included clay content, plant organic carbon, soil organic carbon and profile bulk density. The other four factors with the lowest grades could be ignored due to their weak influence on the temporal stability.

The reason that the four revegetational types, KOP, ALF, NAF and MIL, differed in their effects on SWS temporal stability could specifically be attributed to the effects of vegetation cover and aboveground biomass. Vegetative cover mainly influenced SWS loss through evaporation while aboveground biomass was related to soil water consumption through root uptake. For ALF, the vegetation cover tended to be relatively stable, due to the low height and almost constant shade density throughout the growing season. In addition, with the increasing age after revegetation, purple alfalfa increasingly consumed more water stored in deeper soil layers. Therefore, the SWS pattern within the 1-m soil layer was more temporally stable.

In the secondary class, clay content affected SWS temporal stability more than the other factors. Since it was in the secondary class, this finding suggested that previous studies that emphasized the importance of clay content might be overestimating its effect on temporal stability of SWS. However, it was more important than those factors that were only indirectly related to aboveground biomass and soil porosity.

## 4. Conclusions

For all the four revegetation types being considered, time-averaged SWS within a depth of one meter differed largely in magnitude. The SWS relative to MIL decreased in the order of KOP (49.4 mm), ALF (32.4 mm) and NAF (14.9 mm), which were mainly caused by the differences in water consuming characteristics. This result implied that shortage of soil water was induced by revegetation and was affected by the plant species.

According to the frequency distributions, most measurement points did not maintain the same rank between the extreme soil water conditions, especially for the points with probabilities of 0.5. However, this result might be mitigated or avoided by increasing the sampling density and/or measuring SWS over a longer period.

Based on the relative difference analyses, the most stable points were those that underestimated the mean SWS of the plots. Moreover, points underestimating the plot-average were less stable for KOP and NAF compared to ALF and MIL. On the condition that points with near-zero and minimal $\sigma(\delta_i)$ were absent, other substitute methods including separating both of them into two independent indices, as well as by employing $ITS_i$ and $\omega_i$, became necessary. The representative points identified by these four methods were very different. However, differences in their advantages in terms of estimating the plot average were less pronounced. In addition, points with the minimal $\sigma(\delta_i)$ were valuable for precisely estimating the mean SWS of the experimental plots, especially when corrected by an equation incorporating $\bar{\delta}_i$ and $s_i$. In addition, the plot-average points derived from the above-mentioned ways tended to be on the middle or above middle slope in the plots, which provided a practical alternative to random sampling intended to find the representative points of the areal mean soil water condition.

Results of Spearman rank correlation coefficients indicated that the temporal stability was generally high for ALF, low for NAF, and lowest for MIL plots while for KOP plots it was intermediate. Multiple comparison of $\sigma(\delta_i)$ also verified the significantly higher temporal stability of ALF. Revegetation types thus had significant effects on the temporal stability of SWS within the first meter of the soil profile. Use of GRA confirmed that revegetation type in terms of its vegetation cover and aboveground biomass were the main factors affecting the temporal stability of soil water.

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