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Temporal stability of surface soil moisture of different vegetation types in the Loess Plateau of China

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ABSTRACT

The temporal stability of soil moisture (TSSM) was widely applied to optimize the soil moisture sampling scheme on a catchment or even larger spatial scale over wet and dry observational periods. However, the integration of the TSSM feature with specific hydrological response at a small plot scale has not been sufficiently researched. This study analyzed the temporal stability of surface soil moisture (0–10 cm) characteristics and corresponding influencing factors of different vegetation types under two typical soil moisture changing processes including wet-to-dry (WTD) and dry-to-wet (DTW), and determined the representative points. A total of 16 microplots (60 × 60 cm each) that were composed of three vegetation types containing *Andropogon*, *Artemisia scoparia and Spiraea pubescens* and bare land cover were selected. And the soil moisture in the central point (CP) and four ambient points (APs) of each microplot were measured during the WTD and DTW processes. The results showed that, 1) from DTW to WTD processes, the distribution of the soil water content in different vegetation types indicated a significant difference. Compared with the soil moisture in the AP or CP area of other vegetation types, the soil water content in tall shrub types (*S. pubescens*) was the lowest. 2) The autocorrelation coefficient indicated that both in the AP and CP areas, the soil moisture of the low shrub types (*A. scoparia*) had a higher temporal stability than that of other vegetation types. However, the soil water content in bare land had the highest temporal fluctuation from the DTW to WTD processes. Additionally, in the CP area, the TSSM of all the vegetation types tended to decrease during the WTD process. 3) Based on the TSSM analysis system that was derived from the principle of probability and statistics, the soil moisture in the low shrub types (*A. scoparia*) most likely provides the best representativeness of the spatial average soil water content of heterogeneous vegetation types. The determination of the representative soil moisture point via the hydrological-trait sampling method could be supplementary and significant for a TSSM study of the available soil water resources in an arid and semi-arid ecosystem.

1. Introduction

Soil moisture is an indispensable stress factor in water-controlled ecosystems (Noy-Meir, 1973). In arid and semi-arid environments, the distribution of soil moisture over a specific observational period has often been studied on many different spatial scales (Bell et al., 1980; Brocca et al., 2010; Lin et al., 2006; Qiu et al., 2001), which have a far-reaching impact on the runoff and sediment generation (Calvo-Cases et al., 2003; Fitzjohn et al., 1998), the dynamic balance of water in the soil–plant–atmosphere continuum of different vegetation types (Rodriguez-Iturbe et al., 2001), and the utilization of available water resources in arid and semi-arid ecosystems. In fact, the complex influencing factors of soil moisture response indicated that the soil water has a high variability at different spatiotemporal scales. As a result, a comprehensive analysis of the variable spatiotemporal characteristics of soil moisture is necessary to understand the behavior of soil water in arid and semi-arid environments. Under this background, the concept of the temporal stability of soil moisture (TSSM) was proposed by Vachaud et al. (1985), and was defined as the time invariant association between the spatial location and statistical parametric values based on the probability density function of the soil moisture.

TSSM specifically indicates that the order of the soil moisture or of the average soil moisture arranged in the spatial pattern does not fluctuate with the observational period (Kachanoski and de Jong, 1988). The succession of the interval observation period, the homogeneity of the spatial distribution of soil moisture, and the coupling of the spatial and temporal patterns of the soil water content constituted the main elements of TSSM research. First, different spatial scales of TSSM studies were systemically investigated by many researchers. These scales ranged from multiple investigated fields scales (300 m^2 per field) (Brocca et al., 2010) to hillslope scales (approximately 900 m^2) (Coppola et al., 2011; Penna et al., 2013), from watershed scales (610 km^2 and 1285 km^2 respectively) to an even larger landscape

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scale (Martinez-Fernandez and Ceballos, 2003; Starks et al., 2006). In the Loess Plateau, many researchers (Gao and Shao, 2012; Hu et al., 2010; Jia and Shao, 2013) have also investigated the TSSM in different watersheds.

Second, aiming to analyze the TSSM characteristics under extreme soil water conditions, the temporal pattern of soil moisture initially focused on two different observation periods representing the wet and dry soil moisture conditions (Grayson and Western, 1998; Grayson et al., 1997). For instance, Penna et al. (2013) systematically reported the TSSM characteristics of different soil depths under hillslope scales during the wet and dry periods in the three years. Heathman et al. (2012) divided the temporal pattern of soil moisture into three patterns—time-averaged, wettest and driest period—and mutually compared corresponding TSSM characteristics at field scale. Other researchers (Brocca et al., 2010; Gomez-Plaza et al., 2000; Williams et al., 2009) also analyzed the TSSM in the wet and dry periods on watershed and landscape scales. However, the TSSM characteristics in the two temporal patterns under different spatial scales are still debatable (Gomez-Plaza et al., 2000; Martinez-Fernandez and Ceballos, 2003; Williams et al., 2009; Zhao et al., 2010), because the main influencing factors of the TSSM—such as topography (Brocca et al., 2007, 2009), soil texture (Cosh et al., 2006; Gao and Shao, 2012; Porporato et al., 2001; Starks et al., 2006), precipitation and vegetation types (Brocca et al., 2009; Jia and Shao, 2013; Mohanty and Skaggs, 2001)—are complicated and vary with the spatial scale.

Third, based on the principle of probability and statistics, Vachaud et al. (1985) introduced a series of indices into the TSSM calculation system that could quantify the TSSM characteristics. Mittelbach and Seneviratne (2012) indicated that the rank stability index could be the best way to characterize the temporal stability pattern through relative long-term measurement of soil moisture. And other TSSM evaluation indices contain the cumulative probability, autocorrelation coefficient, and mean/standard deviation of relative differences, which were derived from the probability density function, time series analysis, and statistical inference respectively. Moreover, other researchers (Jacobs et al., 2004; Penna et al., 2013; Zhao et al., 2010) further integrated these statistical methods and defined the index of temporal stability. And some new mathematical tools were also used to analyze the TSSM, such as the combination of climate simulation with TSSM characteristics (Matinez et al., 2014), geostatistical method (Brocca et al., 2009), spatial autocorrelation technique (Biswas and Si, 2011) and wavelet coherency analysis algorithm. The integration of these TSSM analysis methods and remote sensing technique could effectively promote the precision of the soil moisture estimation at large spatial scales

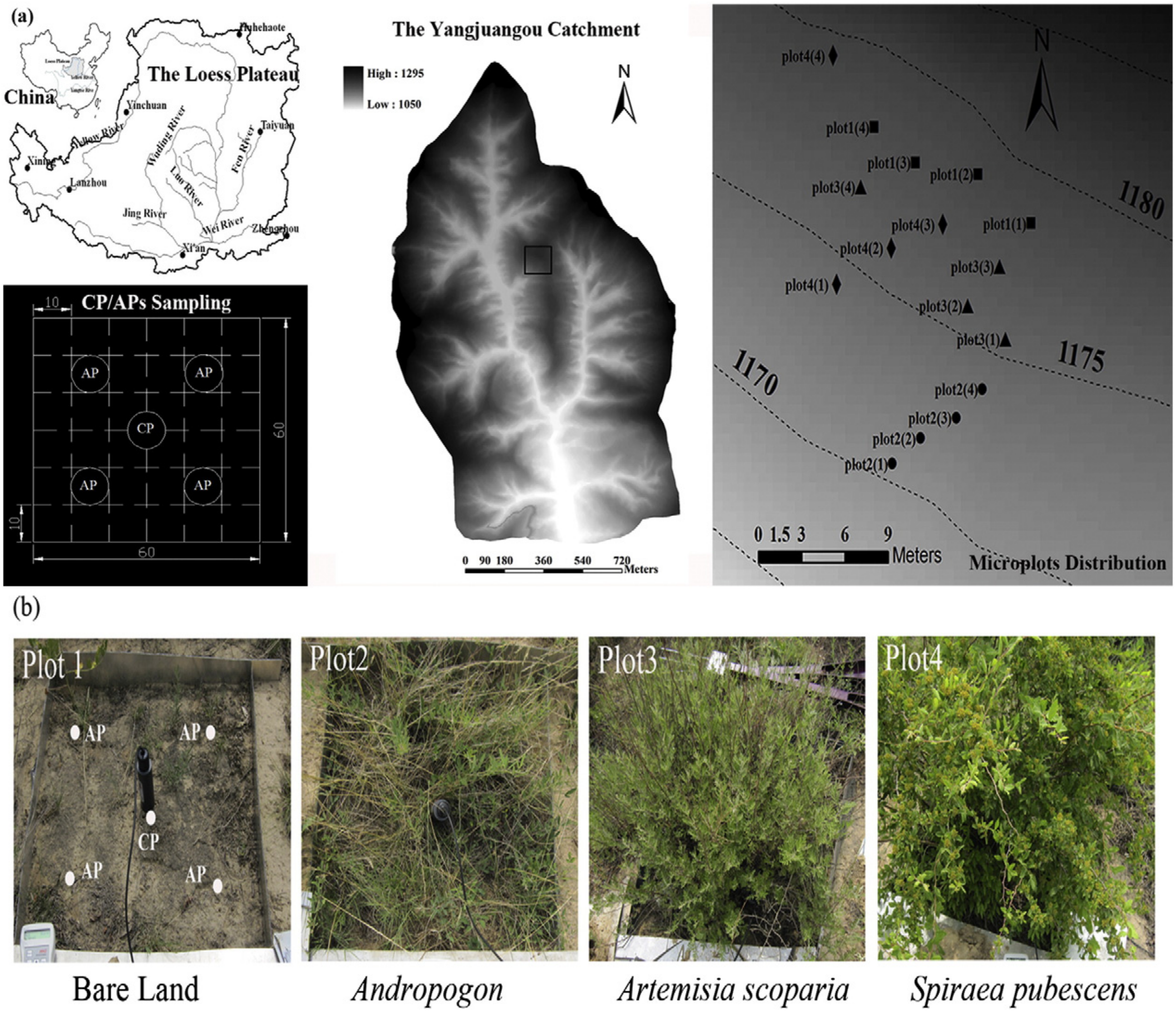

Fig. 1. Description of research area and hydrological process-trait sampling method. (a) Study area and CP/APs' sampling sketch, (b) four types of microplot. The black square, round, triangle and diamond dispersing topographic map represent four different types of microplot including the bare (plot 1), *Andropogon* (plot 2), *Artemisia coparia* (plot 3), and *Spiraea pubescens* (plot 4) respectively. For each type there are four microplots whose codes were displayed in parentheses. Black circle represents the CP/APs circle area whose radius was near 5–8 cm.