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Research papers

Soil moisture dynamics and dominant controls at different spatial scales over semiarid and semi-humid areas

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ABSTRACT

Soil moisture dynamics plays an active role in ecological and hydrological processes, and it depends on a large number of environmental factors, such as topographic attributes, soil properties, land use types, and precipitation. However, studies must still clarify the relative significance of these environmental factors at different soil depths and at different spatial scales. This study aimed: (1) to characterize temporal and spatial variations in soil moisture content (SMC) at four soil layers (0–40, 40–100, 100–200, and 200–500 cm) and three spatial scales (plot, hillslope, and region); and (2) to determine their dominant controls in diverse soil layers at different spatial scales over semiarid and semi-humid areas of the Loess Plateau, China. Given the high co-dependence of environmental factors, partial least squares regression (PLSR) was used to detect relative significance among 15 selected environmental factors that affect SMC. Temporal variation in SMC decreased with increasing soil depth, and vertical changes in the 0–500 cm soil profile were divided into a fast-changing layer (0–40 cm), an active layer (40–100 cm), a sub-active layer (100–200 cm), and a relatively stable layer (200–500 cm). PLSR models simulated SMC accurately in diverse soil layers at different scales; almost all values for variation in response (R^2) and goodness of prediction (Q^2) were > 0.5 and > 0.0975, respectively. Upper and lower layer SMCs were the two most important factors that influenced diverse soil layers at three scales, and these SMC variables exhibited the highest importance in projection (VIP) values. The 7-day antecedent precipitation and 7-day antecedent potential evapotranspiration contributed significantly to SMC only at the 0–40 cm soil layer. VIP of soil properties, especially sand and silt content, which influenced SMC strongly, increased significantly after increasing the measured scale. Mean annual precipitation and potential evapotranspiration also influenced SMC at the regional scale significantly. Overall, this study indicated that dominant controls of SMC varied among three spatial scales on the Loess Plateau, and VIP was a function of spatial scale and soil depth.

1. Introduction

Soil moisture dynamics is a significant variable that is related to a series of hydrological and soil biochemistry processes and vegetation growth (Istanbulluoglu and Bras, 2006; Turcu et al., 2005; Schwinning et al., 2004). Characterizing soil moisture variations is important for both theoretical and practical applications in arid and semiarid ecosystems (Rodriguez-Iturbe and Porporato, 2005). However, soil moisture exhibits high spatial and temporal variability. Hence, knowledge of soil moisture and its spatiotemporal dynamics contributes significantly to rational management of water resources and land practices, such as vegetation restoration projects on the Loess Plateau in China (Gao et al., 2013).

A large number of environmental factors control soil moisture, which results in variability of spatial and temporal distributions. These factors include climate (Henninger et al., 1976; Famiglietti et al., 1998; Zhu et al., 2014; Danelichen et al. 2016), soil properties (Hawley et al., 1983; Wendroth et al., 1999; Cantón et al., 2004; Poltoradnev et al., 2016), topography (Nyberg, 1996; Zhu and Lin, 2011), and land use (Jawson and Niemann 2007; Zhao et al., 2011; Huang et al., 2016) (Table 1). However, it is difficult to identify the relative significance of these factors, due to their mutual and multiple influences on soil moisture. Some influential factors exhibited interdependence at multiple spatial scales and at different soil depths (Zhao et al., 2011; Zhu and Lin, 2011).

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Table 1
Main nature conditions of previous studies on soil moisture variation (in chronological order).

Authors	Location	Climate	Scale	Depth (cm)	Main influence factors	Main analysis method/ model used
Henninger et al. (1976)	Pennsylvania, USA	–	Catchment	15	Precipitation, soil series	Multiple regression equations
Hawley et al. (1983)	Oklahoma, USA	Humid	Catchment	15	Topography, land cover, and soil properties	Statistical analysis
Nyberg (1996)	Gårdsjön, Sweden	Humid	Catchment	30	Topography	Semi-variogram models
Crave and Gascuel-Odous (1997)	Brittany, France	–	Catchment	10	Topography, soil series	Digital elevation model
Seghieri et al. (1997)	Niger	Semiarid	Hillslope	560	Soil surface crusts, vegetation patterns	Principal component analysis
Famiglietti et al. (1998)	TX, USA	Humid–subtropical	Hillslope	5	Topography, soil attributes, and rain events.	Correlation analyses
Wendroth et al.(1999)	Brandenbur, Germany	Semiarid	Hillslope	30	Soil properties	Spherical description of variogram
Gómez-plaza et al. (2001)	Murcia, Spain	Semiarid	Catchment	15	Vegetal cover, soil texture, topography, and contributing area	Correlation analysis
Wang et al. (2001)	Shaan'xi, China	Semiarid	Catchment	75	Precipitation and depth	Geostatistical analysis
Cantón et al. (2004)	Almería, Spain	Semiarid	Hillslope	30	Soil properties, topography, and soil cover	ANOVA and correlation analysis
Jawson and Niemann (2007)	Southern Great Plains, USA	–	Region	5	Soil texture, land use, and topography	Empirical orthogonal function analysis
Zhu and Lin (2011)	Pennsylvania, USA	–	Plot, hillslope, and entire farm	80	Soil properties and topography	Stepwise multiple linear regression
Zhao et al. (2011)	Inner Mongolia,China	Semiarid	Catchment	6	Topographical variables, soil properties, and plant type	ANOVA multiple comparison and multivariate geostatistics
Crow et al. (2012)	–	–	Field, Catchment and regional	20	Soil texture, topographical variables, land use and meteorological	Time stability, Block kriging and Land surface modeling
Zhu et al. (2014)	Hubei, China	Humid	Catchment	15	Precipitation events, soil properties. and land use type	Two-way indicator species analysis and redundancy analysis
Huang et al. (2016)	Hubei, China	Humid	Catchment	85	Soil properties, terrain attributes, land use types, and precipitation	Partial least squares regression
Danelichen et al. (2016)	Mato Grosso, Brazil	Humid	Two plots	10	Precipitation, vegetation. and water indices	Spearman correlation matrix
Poltoradnev et al. (2016)	Kraichgau, Germany	Humid	Tworegions	15	Rainfall and soil properties	Statistical analyses
This study	Loess Plateau, China	Semiarid and semi-humid	Plot, hillslope, and region	500	Soil properties, terrain attributes, vegetation, and climatic characteristics	Partial least squares regression