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Water retention curve correction using changes in bulk density during data collection

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A B S T R A C T

Soil shrinkage commonly occurs during centrifugation for soil water retention curve (SWRC) measurement. This phenomenon increases bulk density and results in a deviation of the SWRC from the true curve, reducing the accuracy of soil water movement simulations. This study considers the change in bulk density during SWRC measurement and corrects for it. Five soils, classified as either loam or sandy loam, were selected as experimental samples from Liaoning, Yunnan, Xinjiang, Shandong, and Shaanxi Provinces of China. Corrected and uncorrected SWRCs were employed in cumulative infiltration simulations to determine whether such a correction is necessary. Results showed that the sample heights decreased as the linear shrinkage ratios increased during dehydration; bulk densities increased relative to the designated values and altered the SWRC. The values of soil moisture for the corrected SWRC were always higher than those for uncorrected SWRC, with an average increment of 6%–18%. SWMS_2D simulations predicted the observed cumulative infiltration values more accurately when using the corrected SWRC than when using the uncorrected SWRC according to the smaller percent bias, root mean square error, and mean absolute percentage error. The results suggested that a correction of the SWRC for changes in bulk density is necessary.

1. Introduction

Soil water is a critical water resource and is therefore a focus of considerable soil physics research (Xing et al., 2017a, 2017b). A better understanding of water movement and distribution in the soil profile can aid scientists in improving soil water-holding capacity and water use efficiency (García et al., 2014; Sorrenti et al., 2016), and promote the development of sustainable dry farming. Water infiltration is the step in the hydrologic cycle that connects overland flow with underground water (Mao et al., 2016). Simulations of water infiltration by modeling soil water transport can reveal the process and mechanism of water movement. The accuracy of water flow predictions obtained from models largely depends on the accuracy of entered soil hydraulic parameters. Accurate simulations reduce field workload and facilitate field irrigation planning. Care should be taken to ensure the accuracy of soil hydraulic parameters when modeling.

The soil water retention curve (SWRC), which describes the relationship between soil suction and volumetric soil moisture, is vital to understanding water transport and water availability in farmland (Karup et al., 2017; Pham and Fredlund, 2008). The derivation of soil hydrodynamic parameters and the simulation of soil water distribution are crucial aspects of soil water movement research. The SWRC is integral to both of these (Hollis et al., 2015; Xing et al., 2017a, 2017b). The SWRC is also an evaluation tool for gap-graded soils and granular soils in engineering geology and an essential input function for modeling the retention and transport of water in the vadose zone of soils (Chiu et al., 2012). Soil hydraulic parameters can be obtained from the SWRC and used as inputs for water movement prediction to simulate the evaporation, infiltration, and runoff dynamics of field soils (Ciocca et al., 2014). Zhai and Rahardjo (2015) determined that the hydraulic properties of soil (calculated using the SWRC and permeability function) controlled the infiltration characteristic of soil. They demonstrated that the estimation of the permeability function from the SWRC was more accurate when considering soil volume change (using degree of saturation), than when ignoring soil volume change (using gravimetric soil moisture). Moreover, Zhai et al. (2017) showed that residual soil moisture could affect the estimation of the permeability function, and by extension, the infiltration characteristics. Other SWRC variables, such as the air-entry value and residual suction, must be determined, because they affect the performance of SWRC equations (Fredlund and Xing, 1994 and van Genuchten, 1980) and the estimation of permeability functions (Zhai and Rahardjo, 2012). Accurate data collection

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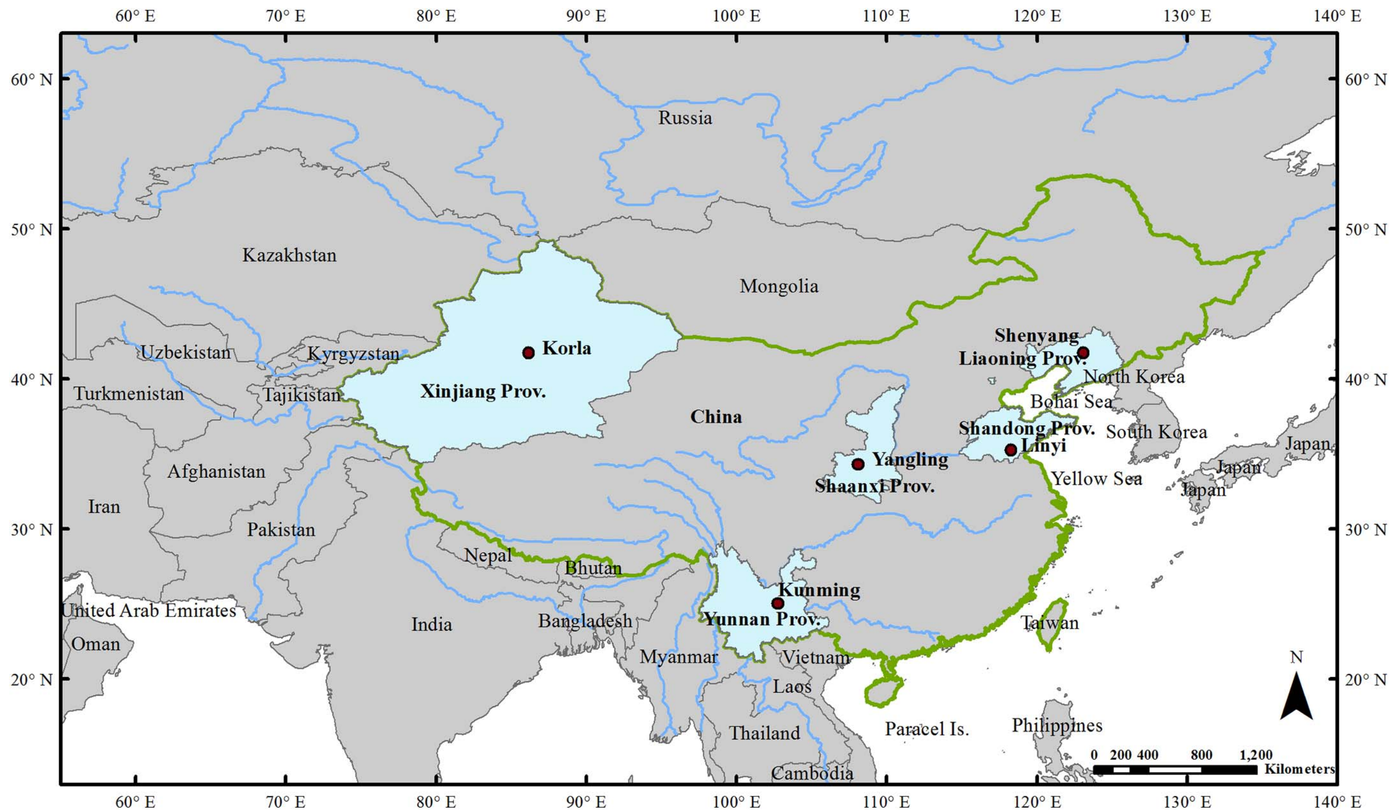

Fig. 1. Locations of the selected experimental soils.

during SWRC construction enhances the accuracy of the hydraulic parameters obtained using the Brooks–Corey, Campbell, or van Genuchten model (Han et al., 2010). Therefore, a correction of the SWRC is imperative to achieve this accuracy. In addition to the SWRC, the permeability function also affects the results of soil water movement simulations (Fredlund et al., 1994; Zhai and Rahardjo, 2015).

Predictions of soil water movement often originate from numerical simulations. HYDRUS commercial modeling software is widely adopted for this purpose (Hou et al., 2016; Kandelous and Šimůnek, 2010; Mguidiche et al., 2015). Another popular simulation tool is SWMS, a Fortran-based open-source software package that simulates the water flow through the vadose zone. The SWMS can solve the Richards equation for saturated–unsaturated water flow and the convection–dispersion equation for solute transport. This software can also analyze water and solute transport in unsaturated, partially-saturated, and fully-saturated porous media. The SWMS is simpler than HYDRUS for modeling soil water dynamics (Yao et al., 2011). For its reliability and flexibility, SWMS_2D was selected to simulate cumulative infiltration in this study.

Soils tend to swell and shrink when subjected to cycles of wetting and drying. This results in a deviation from the in situ bulk density values (Fu et al., 2011). Soil exhibits compressibility during centrifugation, which results in contraction under the effects of centrifugal force. This leads to changes in bulk density similar to those encountered with the tensiometer technique (Boivin et al., 2006; Braudeau et al., 2005; Coquet, 1998) and the pressure plate technique (Lu et al., 2004). Soil shrinkage due to dehydration under centrifugal force is usually ignored when using the centrifuge, and the soil bulk density is assumed to be constant (Mohammadi and Meskini-Vishkaee, 2013; Zhou et al., 2014). This assumption decreases the accuracy of the SWRC, because underestimation of volumetric soil moisture introduces errors in the hydraulic parameter prediction for modeling water transport in soils. During dehydration, soil shrinkage leads to an increase in bulk density, further increasing volumetric soil moisture and altering the SWRC. Empirical studies have indicated that SWRC is correlated with bulk density. Regression analysis can be used to predict hydrologic properties from routinely measured textural and structural soil properties, and this method has been adopted as an alternative to the experimental approach. Gupta and Larson (1979), Arya and Paris (1981), and Vereecken et al. (1989) have used pedotransfer functions to relate water content to soil bulk density at specified soil water pressures. Generally, however, soil shrinkage is ignored during SWRC data collection. Soil shrinkage has practical relevance and should be accounted for during SWRC measurements. Although the effect of bulk density on soil moisture retention has been reported to some extent, this effect has not received sufficient research attention. Therefore, this study further investigates how changes in bulk density affect the SWRC and water infiltration modeling.

Studies have demonstrated that an increase in bulk density during centrifugation causes a disparity between the measured and actual SWRCs. Therefore, this should be considered during SWRC construction. The main purposes of this study were (1) to comparatively evaluate the shrinkage and SWRC, both ignoring and considering the change of soil bulk density, and (2) to investigate the effect of corrected and uncorrected SWRCs on cumulative infiltration simulations using SWMS_2D.

2. Materials and methods

2.1. Soil samples

Loam and sandy loam (based on the United States Department of Agriculture Soil Taxonomy System) were selected from five regions in China as experimental soil samples. The sample collection regions included Shenyang in Liaoning Provinces (41°44′N, 123°06′E), Linyi in Shandong Province (35°17′N, 118°17′E), Yangling in Shaanxi Province (34°17′N, 108°04′E), Kunming in Yunnan Province (25°02′N, 102°43′E), and Korla in Xinjiang Province (41°45′N, 86°10′E), as shown in Fig. 1.