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Evaluation of soil water retention pedotransfer functions for Vietnamese Mekong Delta soils

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ABSTRACT

Appropriate management of irrigation and drainage, which require the information of soil water retention characteristics (SWRC), is of crucial importance for sustainable paddy rice production in tropical deltas. SWRC, however, is usually missing due to the lack of facilities, cost, and personnel training involved in direct measurement methods. Pedotransfer functions (PTFs) that provide the estimation of SWRC from other basic soil properties are the alternative source of SWRC for practical soil water managements or modeling purposes. Since developing new PTFs is a very arduous task which requires a large soil database of good quality, utilizing existing PTFs where possible is highly recommended. The objective of this study was therefore to evaluate the applicability and reliability of published SWRC-PTFs for soils in tropical Vietnamese Mekong Delta (VMD) where paddy rice is the main agricultural practice. A number of well-known statistical regression and pattern-recognition PTFs were selected for the evaluation. By assessing the correspondence between measured and PTF predicted values of SWRC, the results show that the PTFs derived from large databases of soils in the regions having similar climatological and pedological conditions to VMD soils are more reliable for predicting SWRC (RMSE varies in the range of 0.06–0.07 $m^3 m^{-3}$, and of 0.05–0.06 $m^3 m^{-3}$ for the prediction of soil water content at −33 kPa and −1500 kPa, respectively). The applicability index together with geographical information, therefore, could be used as integral indicators to select appropriate PTFs in cases no SWRC data are available for timely uses. Detailed evaluation of PTFs' performance however revealed the limited potential of investigated PTFs to VMD soils. Further researches to develop specific PTFs for tropical delta soils are recommended for accurate SWRC estimation in such regions.

1. Introduction

Irrigated paddy rice is estimated to receive some 34–43% of the total world's irrigation water, or 24–30% of total world's fresh water withdrawals (Bouman et al., 2007). With increasing water scarcity, the sustainability, food production, and ecosystem services of rice fields are threatened. Therefore, optimal soil water management practices in terms of irrigation and drainage that can help farmers to cope with water scarcity in irrigated environments are urgently needed.

Information on soil hydraulic properties (e.g., soil water retention and soil hydraulic conductivity) are crucial in solving many soil water management problems related to agricultural, hydrological and environmental issues. Moreover, since soil hydraulic properties are the governing factors of retention and transport of water and chemicals in the vadose zone, they are integral inputs in operating a wide range of agro-hydrological models, e.g., AquaCrop (Steduto et al., 2009), HYDRUS (Šimůnek et al., 2012), DRAINMOD (Tian et al., 2012), RZWQM (Hanson et al., 1998) to mention a few.

Soil water retention characteristic (SWRC), which expresses the functional relationship between soil matric potential and its corresponding gravimetric or volumetric water content (Or and Wraith, 2002), can be measured directly in the field or in the laboratory.

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The information of SWRC, however, is usually missing in most soil databases, due to its cumbersome and expensive measurement methods (Rawls and Brakensiek, 1982). The dearth of this information in developing countries located in the tropics is even worse than elsewhere due to additional problems linked to personnel training and acquisition of needed equipment for these measurements (Medina et al., 2002). In order to circumvent the missing gap, several efforts have been devoted to predicting SWRC from easily accessible soil properties using pedotransfer functions (PTFs).

Until recently, most of soil water retention PTFs available in the literature have been derived from soils in temperate regions (Tomasella and Hodnett, 2004), e.g., the PTFs of Gupta and Larson (1979), Lamorski et al. (2008), Nemes et al. (2008), Rawls and Brakensiek (1982), Saxton and Rawls (2006), Saxton et al. (1986), Schaap et al. (2001), Twarakavi et al. (2009), and Vereecken et al. (1989). Much less studies have been devoted to soils in the tropics (Botula et al., 2012), particularly tropical humid deltas where paddy rice cultivation is the main agricultural practices. The need of accurate and up-to-date information of soil hydraulic characteristics in the tropics is even more urgent than in other regions, especially under the context of global climate change (Minasny and Hartemink, 2011) because soil data in these regions are often sparse and outdated. The lack of well-defined and extensive databases with hydraulic properties data is generally identified as the main constraint dragging the development of 'tropical soils' PTFs behind (Hodnett and Tomasella, 2002).

Since developing new PTFs is a very arduous task which generally requires a large soil database of good quality (Minasny et al., 2008), using existing functions where possible is thus highly recommended. However, many PTFs have limited applicability, i.e., they have been derived for specific soils within a limited geomorphic and geographic domain and have been intended for a regional application. Specific PTFs might be accurate for the original training data, but unreliable for soils in other contexts (Wösten et al., 2001). As have been shown in several evaluation studies, e.g., Botula et al. (2012) and Nebel et al. (2010), the prediction performance of PTFs could be influenced by the geographic preference of the source data set. Additionally, Hodnett and Tomasella (2002) also cautiously noted the risks of applying PTFs developed using temperate soil databases to soils of the tropics. They observed marked differences between parameters which describe soil water retention behavior of soils in temperate and tropical climates. Such differences have been attributed to the discrepancy in terms of chemical, physical and mineralogical properties between soils. Indeed, although the soil forming factors are similar in both temperate and tropical climates, the extent of these factors is different (Lal, 2000). High prevailing temperature and intensive rainfall in the humid tropics result in strong weathering and leaching processes in large areas of the regions (loss of Ca, Mg, Na and K, accumulation of Fe and Al) and tend to create particular mineralogies and soil structure that are less common in temperate regions (Hodnett and Tomasella, 2002).

Moreover, the determination of SWRC is not a goal in itself, but rather aims at providing essential input data for simulation models in agricultural, hydrological and environmental studies (Minasny and Hartemink, 2011). Inaccurate estimation of this soil property may consequently influence the overall quality of the outputs of the whole modeling process (Botula et al., 2012). Cornelis et al. (2001) and McBratney et al. (2002), among others, warned that the extrapolation of PTFs beyond the statistical limits of the calibration data set and the geographical locations of soils from which they were developed should be avoided or at least carefully evaluated for their predictive quality.

It is important, therefore, to test cautiously the applicability and predictability of published PTFs by using a limited number of measured SWRC from the site of interest (Espino et al., 1996; Minasny et al., 2008). A major part of published evaluation studies in the literature have assessed PTFs developed for soils from temperate regions using independent data sets also from temperate climates (Buccigrossi et al., 2010; Cornelis et al., 2001; Kern, 1995; Tietje and Tapkenhinrichs, 1993). Only a limited number of studies have been conducted with the evaluated data sets of soils from humid and sub-humid tropics (Botula et al., 2012; Reichert et al., 2009; Tomasella and Hodnett, 2004). Additionally (Nemes et al., 2006) noted that most evaluation studies of published PTFs using independent data sets in the literature remain unclear about the main sources of estimation errors. The difference between data sets used to derive PTFs, difference in the algorithms of PTF development, or difference among the predictors used might probably result in the overall error of prediction.

Therefore, the objectives of this study were to evaluate (1) the applicability and (2) reliability of a number of published SWRC-PTFs derived from soils in both temperate and tropical climates for the Vietnamese Mekong Delta (VMD) soils, and (3) to clarify the main sources of prediction error when using existing PTFs for soils in the tropical delta. To our knowledge, this is the first study focusing on evaluation of performance of existing PTFs for prediction of soil water retention property of a wide variety of soils in a delta dominated by paddy rice cultivation. This evaluation is important since it addresses the need of improving existing PTFs or developing new PTFs to offer more accurate estimations of SWRC in such regions.

2. Materials and methods

2.1. Study area

The study was conducted in the VMD, which spreads from a latitude of 8°30′ N to 11°00′ N, and a longitude of 104°30′ E to 106°45′ E. The delta occupies a great part of the downstream area of the Mekong River (Fig. 1) and is characterized by perpetual sedimentation at the latter's mouths. This wide and flat plain covers an area of 3.96 million hectares (about 12% of the total natural land area of Vietnam), in which 1.85 million hectares have been used for paddy rice cultivation (Tran et al., 2007).

The Mekong Delta has a monsoon tropical climate with two distinct seasons: a wet season (summer monsoon with South-Western wind direction) from May to November with high precipitations (about 90–94% of the total rainfall over the year), and a dry season (winter monsoon with North-Eastern wind direction) from December to April. Average annual rainfall in the delta ranges from 1400 mm (±350 mm) in the central area to 2400 mm (±240 mm) in the western part, while the eastern part receiving on average 1600 mm (±220 mm) of rainfall. Temperature in the delta is high and stable, ranging from 26 °C to 28 °C across the entire area. Evaporation is about 1100–1400 mm depending on the specific topography of the area. The relative humidity ranges from 79% to 85% (Le, 2003).

Generally, climatic and hydrological conditions of VMD have strong impacts on the soil forming processes as well as the partial and temporal variability of VMD soils (Le, 2003). In the dry season, the rainfall is small (10% of the annual rainfall), the river discharge is low, and evaporation is rather high (around 150–220 mm/month) causing severe water imbalance (Estellès et al., 2002). These conditions promote inland salinity intrusion (about 40–50 km far away from the sea-shores) and the change of potential acid sulfate soils into actual ones (Vo and Nguyen, 2012). In the rainy season with water surplus, salts and sulfuric acids are leached making these problem soils become suitable for agricultural production.

Pedologically, most of the soils in the VMD are formed and developed during the Holocene period. Except for the minor area in the eastern and northern parts of the delta consisting of old Pleistocene