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# Estimating soil hydraulic properties of Fengqiu County soils in the North China Plain using pedo-transfer functions

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**Abstract**

The unsaturated soil hydraulic characteristics, including soil water retention curve and hydraulic conductivity, are the crucial input data for simulating soil water and solute transport through the unsaturated zone at regional scales using GIS, and are expensive to measure. These properties are frequently predicted with pedo-transfer functions (PTFs) using the routinely measured soil properties (e.g. soil texture, soil bulk density, and soil organic matter content).

In this study, 63 soil water retention curves and 36 saturated soil hydraulic conductivities of seven soil profiles collected in Fengqiu County in the North China Plain were measured. Soil texture, bulk density and soil organic matter of these soil samples were also measured. The van Genuchten model describing soil water retention was used to fit the measured data for quantifying the soil hydraulic parameters. The PTFs were developed by multiple regression between soil hydraulic parameter data and basic soil properties. The double cross-validation of these PTFs is also discussed in this paper. The locally-developed PTFs from this study were compared with several existing PTFs in predicting the soil hydraulic parameters.

The developed PTFs were used in the regional simulation of a wheat and maize cropping agroecosystem in Fengqiu County for the 1998–1999 rotation year, and can explain 33% of spatial variation of the observed crop yields in 409 villages.


*Keywords:* Soil water retention curve; Saturated soil hydraulic conductivity; Basic soil properties; Pedo-transfer functions; Multiple regression; Application

## 1. Introduction

A spatially distributed model of water and nutrient management (WNMM) has been developed to study the impact of intensive cropping systems on water resource quality in the North China Plain (Li, 2002). Because dynamic water flow and nitrate transport through the soil vadose zone are modelled in WNMM, it requires that the soil hydraulic properties be known at regional scales. The hydraulic properties include the soil water retention curve (SWRC), which presents the relationship between the volumetric water content ($\theta$) and the soil water pressure head ($h$), and the hydraulic conductivity curve, which relates the conductivity ($K$) to the soil water pressure head ($h$) or the water content.

When the temporal and spatial variability of the region is considered, the required measurements of unsaturated soil hydraulic properties are tremendous, time-consuming, and very expensive. Therefore, it is necessary to develop a set of so-called pedo-transfer functions (PTFs) to estimate the unsaturated soil hydraulic properties from more easily measured or basic soil properties in the attribute database of a digital soil survey map, in which soil hydraulic properties are not always available. Bouma and van Lanen (1987) first described the equations for relating different land characteristics and soil properties as the term PTFs even though there were many attempts in this field before. For the recent development of PTFs and their application, we refer to reviews by Rawls et al. (1991), van Genuchten and Leij (1992), Pachepsky et al. (1999) and Wösten et al. (2001).

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In developing PTFs, soil texture (including sand, silt and clay contents), bulk density and organic mater content are the most used predictors in the literatures, and additional factors (soil particle size and distribution indices) are rarely applied because of lack of availability in the soil databases (Wösten et al., 2001). Furthermore, as summarized by Nemes et al. (2003), most of PTFs are developed to estimate the soil water retention (points at a series of matric potentials or parameters of analytical water retention equations) and saturated hydraulic conductivity. A small number of PTFs were proposed for the estimation of unsaturated hydraulic conductivity, e.g. Wagner et al. (2001). Methods for predicting soil hydraulic characteristic using PTFs are grouped by Tietje and Tapkenhinrichs (1993) into three types: (i) estimation of the water contents at certain matric potentials (Husz, 1967; Renger, 1971; Gupta and Larson, 1979; Rawls et al., 1982; Puckett et al., 1985; Imam et al., 1999; Kar et al., 2004), (ii) estimation of soil water retention relation with a physical–conceptual model approach (Arya and Paris, 1981; Haverkamp and Parlange, 1986; Tyler and Wheatcraft, 1989; Baumer, 1992; van den Berg et al., 1997; Tomasella and Hodnett, 1998; Tomasella et al., 2003), and (iii) estimation of parameters of algebraic retention functions for describing $\theta(h)$ and $K(\theta)$ or $K(h)$ (Pachepsky et al., 1982; Cosby et al., 1984; Rawls and Brakensiek, 1985; Nicolaeva et al., 1986; Wösten and van Genuchten, 1988; Rawls and Brakensiek, 1989; Vereecken et al., 1989, 1990; Schaap et al., 1998; Minasny et al., 1999; Wösten et al., 1999; Tomasella et al., 2003). The third method is widely used to directly predict hydraulic model parameters for describing soil water retention and hydraulic conductivity properties. PTFs are usually expressed as linear or nonlinear regression equations or, more recently, distributed as computer codes resulting from artificial neutron network analysis (Pachepsky et al., 1996; Tamari et al., 1996; Schaap and Leij, 1998; Minasny et al., 1999; Schaap et al., 2001; Nemes et al., 2003).

If van Genuchten models (van Genuchten, 1980) for soil water retention and soil hydraulic conductivity, based on the statistical pore-size distribution model of Mualem (1976), are applied in modelling, the parameters representing the soil hydraulic conductivity curve can be the same or directly derived from the soil water retention parameters, except for the saturated soil hydraulic conductivity ($K_s$). This eliminates the need for the direct measurement or indirect estimation of the hydraulic conductivity curve if $K_s$ is known. Hence, the van Genuchten models of soil water retention and unsaturated soil hydraulic conductivity are considered in this study.

Because existing PTFs for estimating soil water retention curve and soil hydraulic conductivity in the literature are not always applicable in other regions with acceptable accuracy (Tietje and Tapkenhinrichs, 1993; Kern, 1995; Tietje and Hennings, 1996; Cornelis et al., 2001; Wagner et al., 2001; Nemes et al., 2003), we based this study on a data set covering measured basic soil properties, soil water retention curves and the saturated hydraulic conductivity of representative Fengqiu County soils in the North China Plain. The objective was to derive our own PTFs for estimating the soil water retention parameters and saturated hydraulic conductivity. The adjusted coefficients of determination and double cross-validation were used to evaluate the predictive capabilities of the derived PTFs, which will be deployed to the digital soil map of Fengqiu

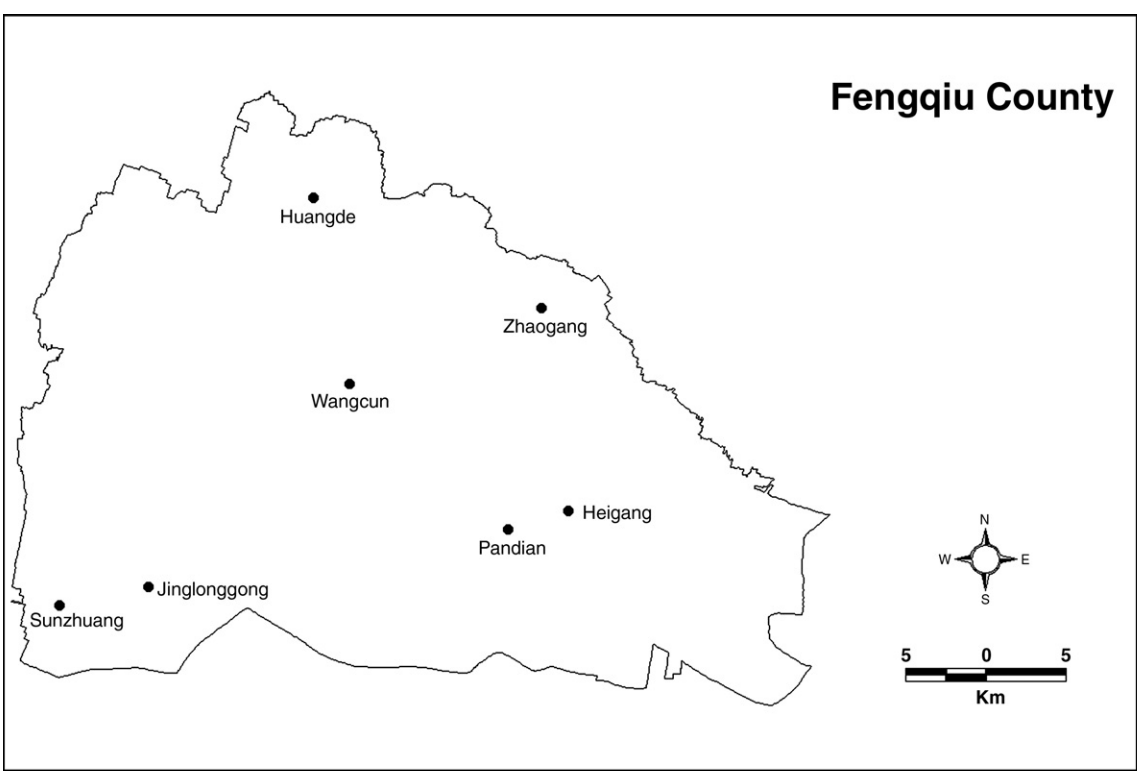


Fig. 1. The sampling sites of seven soil profiles in Fengqiu County.