擴展基於物理模式建立之土壤水力參數轉換方程式在臺灣土壤適用性

Extending soil hydraulic parameter pedotransfer function based on physical models on the applicability of Taiwan soil

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摘要

土壤水力參數對於研究入滲、保水、蒸發等過程具有極其重要的影響力，在農業、水文、生態、土壤物理等許多領域中，皆會使用土壤水力參數進行後續的分析與研究。所以若能有效且正確的評估土壤水力參數，對於不同領域在各方面的應用上都會有顯著的益處，因此也為各個領域皆須解決的問題。

傳統獲取土壤水力參數主要是以實驗測得。然而此作法曠日廢時，推求一筆土樣之完整土壤水分特性曲線，常需耗費兩星期至一個月。對於現地工作、研究等需要初步的土壤水力參數，以判斷後續目前工作現況與成果顯然是緩不濟急。因此早期研究人員開發許多不同的土壤轉換方程式，包括線性回歸、非線性擬合、數學物理模型、類神經網路(Artificial neural network，ANN)、K-近鄰演算法(k-nearest neighbors，k-NN)。其中物理模式因為自變數與應變數背後的機制明確，在實驗設計、研究中有更加廣泛的應用性。因此，本次研究將著重在物理模型之轉換方程式。

本研究方法將以 van Genuchten 模式作為土壤水分特性曲線函數。蒐集彙整近五年的土壤轉換方程式文獻，從中挑選效率較佳的數個轉換方程式，搭配臺灣本地的土壤資料共 2614 筆(去除部分異常值，包括土壤水分含量隨著基質勢能降低而增加、砂粉黏重量百分比總和不為 1、統體密度<1g/cm^3、有機質重量百分比>40%)。透過粒徑分布(砂粉黏比例)、總體密度、有機質含量等土壤基本性質，以均方根誤差(root mean square error，RMSE)當作判定指標，分析土壤水分特性曲線在不同轉換方程式的成功率。挑選出表現較佳的轉換方程式後，以推估之田間含水量減去永久凋萎點計算推估之有效水分誤差(田間含水量的基質勢能為-0.1bar、永久凋萎點的基質勢能為-15bar)。繪出有效水分誤差直方圖並配合統計學的假設檢定、拔靴法，評估有效水分含量誤差及其信賴區間。

研究結果顯示在臺灣本地土壤共 2614 筆中，Tian et al. (2018)以總體密度為參數進行轉換之連續型方程式具有較佳的適用性，其中一筆資料的結果呈現如圖 1。圖中可見 Tian et al. (2018)的方法轉換成果較其他轉換方程式優異，此方法可以解決資料缺失或異

常時無法評估土壤水力參數的問題。透過拔靴法可再進一步分析有效水分含量誤差，如圖 2 所示。從圖中可以確認轉換方程式轉換誤差期望值為 0 即不偏估(unbiased)，且約 95%資料的有效水分含量誤差介於-0.12~0.18。此誤差主要源自量測資料的變異性與參考土樣的選擇。未來如果能夠透過改善資料品質與精進參考土樣的選擇，則可以有效地降低預測誤差。

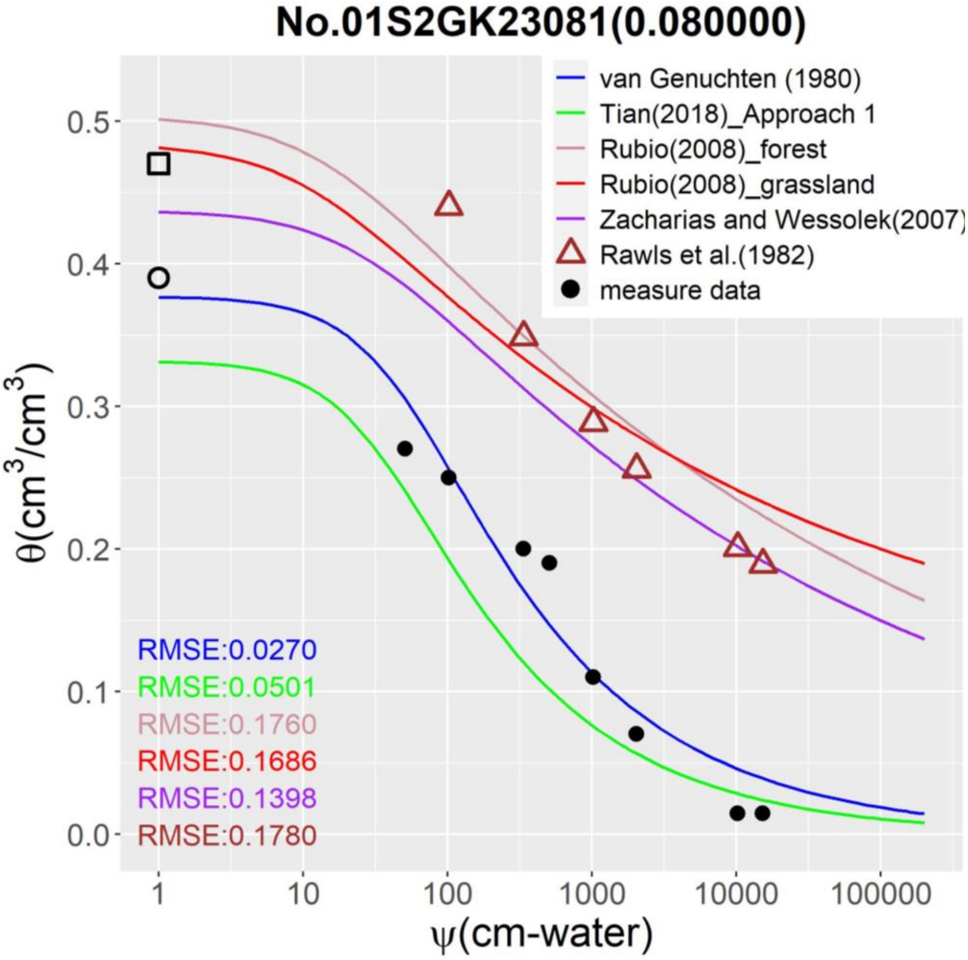

圖 1 樣本編號 01S2GK23081 的水分特性曲線。縱軸為土壤水分含量、橫軸為基質勢能(絕對值，對數軸)。黑點為觀測資料，黑空心圓為飽和含水量，黑方框為孔隙率。不同顏色的線代表不同轉換方程式。

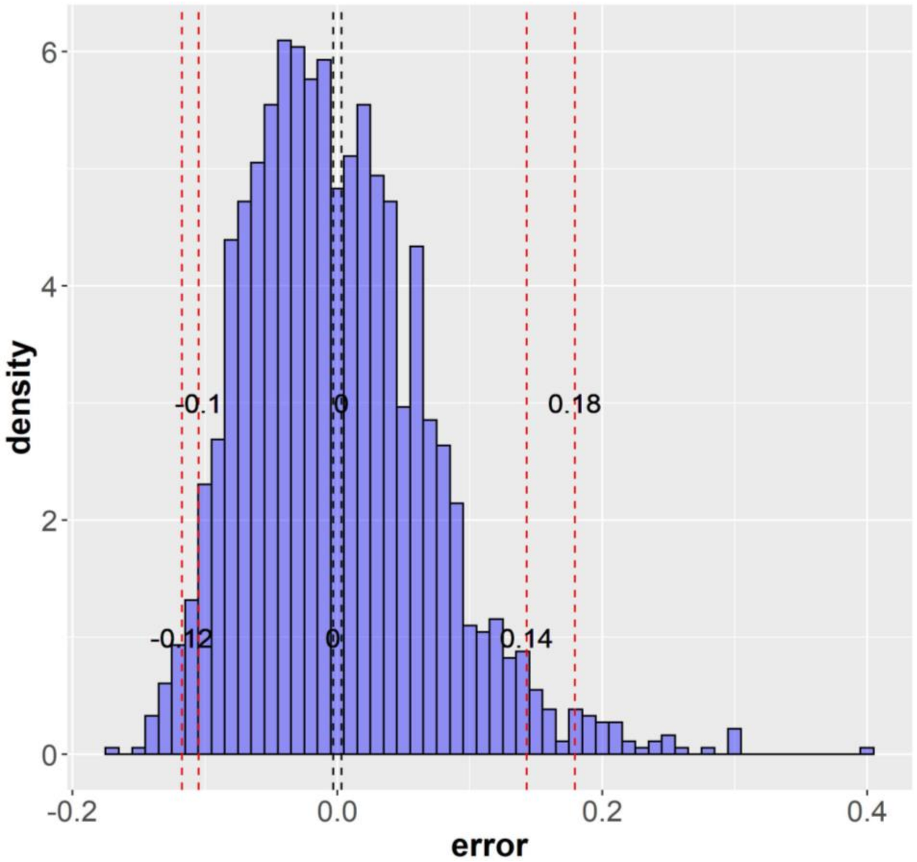

圖 2 臺灣本地土壤共 2614 筆之有效水分含量誤差直方圖。縱軸為密度(無因次)，橫軸為有效水分含量誤差(cm^3/cm^3)。由左到右依序為 2.5 百分位數、平均值、97.5 百分位數的 95%信賴區間。

關鍵詞：水分特性曲線，有效水分含量，參數化，van Genuchten 模式，拔靴法

Abstract

Soil hydraulic parameters play an important role on the study of infiltration, water retention, evaporation and other processes. In agriculture, hydrology, ecology, soil physics and other fields, soil hydraulic parameters are used for subsequent analysis and research. Effective and correct evaluation of soil hydraulic parameters will have great advantage for applications in various fields, and therefore is a problem that must be solved.

The traditional method is mainly to measure soil hydraulic parameters through experiments. However, this method takes a long time, and it usually takes two weeks to a month to deduce the complete soil water characteristic curve of a soil sample. Therefore, early researchers developed many different pedotransfer function(PTF), including linear regression, nonlinear fitting, physical models, artificial neural networks (ANN), and k-nearest neighbors (k-NN). Among them, the physical model has a wider application in experimental design and research because the mechanism behind the independent variable and dependent variable is clear. Therefore, this research will focus on the pedotransfer function of the physical model.

This research will use the van Genuchten model as the soil water characteristic curve, and review the literature on soil pedotransfer function in the past five years, then select several pedotransfer function with better efficiency for analysis with 2614 rows local soil data in Taiwan(excluding abnormal data, such as increasing of soil moisture content with decreasing of matrix potential, sum of texture content not equals to 1, bulk density smaller than 1g/cm^3, organic matter content larger than 40%). Through the basic soil properties such as particle size distribution, bulk density, organic matter content, and using root-mean-square error (RMSE) as the metrics, for analyzing different PTF. After selecting the PTF with better performance, the estimation of available water content is calculated by subtracting permanent wilting point from field capacity (the matrix potential of field capacity is -0.1 bar, the matrix potential of the permanent wilting point is -15bar). Next, draw a histogram of the available water content error, and use statistical hypothesis test and bootstrap method to evaluate the error and its confidence interval.

The research results show that the continuous pedotransfer function (Tian et al., 2018) with the bulk density as a parameter has better applicability with 2614 rows local soil data in Taiwan, one of the data analysis is shown in Figure 1. It can be seen from the Figure 1. that the approach of Tian et al. (2018) are better than other approaches. This approach can solve the problem that soil hydraulic parameters cannot be evaluated when data is missing or abnormal. The available water content error can be further analyzed by the bootstrap method, as shown in Figure 2. It shows that the expected value of the available water content error nearly equal to 0, that is, unbiased, and the error range of 95% rows data(2614*95%) is about -0.12~0.18(cm^3/cm^3). Error is mainly due to the variability of measurement and the selection of reference soil samples. In the future, if the data quality and the selection of reference samples can be improved, the error of prediction can be greatly reduced.

Keywords: soil water characteristic curve，available water content，parameterized，van Genuchten model，bootstrap method