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Research Application Summary

Parametric pedotransfer functions for predicting soil water retention in a Ngerengere Subcatchment, Morogoro -Tanzania

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Abstract

The soil water retention-release characteristics (SWRC) are essential to understand water redistribution in agricultural systems. However, direct measurements of SWRC are constrained by costs, scarcity of equipment and time. Pedotransfer functions (PTFs) are proposed as a simplified indirect alternative. The gist of this work was to assess the efficacy of selected parametric PTFs for prediction of SWRC based on the Van Genuchten parameters (θs, α, n). Lowest prediction bias was for ès (ME; 0.0574 to 0.1249cm^{3}cm^{-3}). Greatest prediction bias was for n (ME; -0.659 to 0.8521). The PTFs showed low reliability (R^2 <15%) necessitating development of locally calibrated PTFs.

Key words: Agricultural systems, Pedotransfer function, Parametric, soil water retention-release characteristics

Résumé

Les caractéristiques de rétention-libération de l'eau du sol(SWRC) sont essentielles pour comprendre la redistribution de l'eau dans les systèmes agricoles. Cependant, des mesures directes des SWRC sont contraintes par des coûts, la pénurie de l'équipement et le temps. Les fonctions de transfert de sol (PTFs) sont proposées comme alternative indirecte simplifiée. L'essentiel de ce travail était d'évaluer l'efficacité de PTFs paramétriques choisies pour la prévision des SWRC basées sur les paramètres de Van Genuchten (qs, a, n). La plus basse polarisation de prévision était prévue (ME; 0.0574 à 0.1249cm3cm-3). La plus grande polarisation de prévision était pour n (ME; -0.659 à 0.8521). Les PTFs ont montré la faible fiabilité (R2 <15%) nécessitant le développement des PTFs localement calibrés.

Mots clés: Systèmes agricoles, fonction de transfert de sol, paramétrique, caractéristiques de rétention-libération de l'eau du sol

Background

Soil water retention is an essential input for modelling soil water regimes in relation to the potential of soil for various land uses (Mdemu and Mulengera, 2002; Baroni *et al.*, 2009). The soil water release-retention characteristics drive the flow of water in the soil-plant-atmosphere system, hence controlling consumptive use, solute transport, aquifer recharge and the quantity of water in natural water reservoirs (Baroni *et al.*, 2009). With the changing climate scenarios in Sub-Saharan Africa (SSA) (ICRAF, 2009), quantifying soil water retention using cost effective approaches will be crucial for understanding the influence of climate on water redistribution in agricultural systems.

Direct investigations for characterization of soil water retention are however costly, time-consuming (Baroni *et al.*, 2009) and the equipment are rarely available in most soil laboratories in the region. Recently, the use of pedotransfer functions (PTFs)-mathematical equations utilising physicochemical soil data to estimate hydraulic parameters has attracted attention. A plethora of PTFs for soil water retention have been developed but mostly for temperate soils (Weynants *et al.*, 2009), and the scanty work for soils within the SSA region has focused on the point PTFs (Mdemu and Mulengera, 2002; Mugabe, 2004), neglecting the more robust parametric PTFs for water balance studies (Merdun *et al.*, 2006). The focus of this study therefore was to validate selected parametric PTFs for prediction of soil water retention for tropical soils, using a Ngerengere sub-catchment in Morogoro as a case study.

Literature Summary

The sigmoidal soil water retention curve describes the soil water retention-release behavior. It is a dependence between the volumetric soil water content and its energy state with an array of numerical models to describe its shape. The Van Genuchten (1980) (VG) model is mostly widely applied (Omuto, 2009). The parameters of VG are èr (cm^3cm^{-3}) and ès (cm^3cm^{-3}), a (cm^{-1}) and n; which respectively represent the residual water content, saturation water content, inverse of the air-entry potential and the pore-size distribution (Omuto, 2009). Pedotransfer functions for the VG model are selected for this study on the basis of their reported accuracy in the areas of development and non-ambiguity of obtaining the required predictor variables.

Study Description

A regular grid of 48 sampling points at 45 m intervals were established on the research field (6°50' S, 37°39' E) at the foot slopes of the Uluguru Mountains. Other samples were also taken at 10 random points within the grid.

At each point, soil samples were taken at two depths; 10-20 cm and 40 cm. The soil samples comprised a bulk sample and two 100cm cores from each depth. Samples were analysed in the laboratory to constitute an overall dataset of 116. The bulk sample was analyzed for texture, CEC, pH and OC. Averaged core sample measurements were used for estimation of bulk density and volumetric water retention at potentials of 0, 20, 60, 100, 200, 300, 800, 6100, 15000 cm using the pressure plate apparatus. The water retention data were run in RETC Software (V 6.02) to derive hydraulic parameters of VG (Mualem restriction; m=1-1/n), with initial θs set as observed from laboratory measurements for all samples. θr was taken as zero for consistency of comparisons of PTFs.

Thirteen samples with α>3 and n<1 were discarded from the overall dataset (n=116) and they reflected erroneous measurements on verification. The remaining dataset was randomly split into two; Validation dataset (62) and Testing dataset (41). The validation dataset was used to evaluate the PTF accuracy for estimating the hydraulic parameters subject to their required inputs. The evaluation indices were mean error (ME), Root mean squared error (RMSE) and the coefficient of determination (R^2). All statistical analyses were performed with MS Excel software.

Findings

Generally all the selected PTFs depicted poor prediction accuracy for the three hydraulic parameters (θs, n, α). Lowest estimation bias was for θs, with low ranges of ME (0.0574-0.1249 cm^3cm^{-3}) and RMSE (0.07-0.132 cm^3cm^{-3}) (Table 1). The Vereecken *et al.* (1989) PTF showed least systematic errors (ME = 0.0574 cm^3cm^{-3}, RMSE = 0.07 cm^3cm^{-3}) between

Table 1. Performance indicators of selected PTFs.

PTFs	α (cm^{-1})			n			θs (cm^3cm^{-3})		
	ME	RMSE	R^2 (%)	ME	RMSE	R^2 (%)	ME	RMSE	R^2 (%)
Weynants *et al.* (2009)	0.4133	0.601	10.15	0.1852	0.219	4.7	0.0981	0.104	2.6
Zacharias and Wessolek (2007)	0.2129	0.472	6.93	-0.659	0.670	7.6	0.0988	0.106	2.6
Wosten *et al.* (1999)	0.4038	0.596	5.04	0.1515	0.196	13.0	0.1249	0.132	2.6
Vereecken *et al.* (1989)	0.4256	0.609	2.75	0.8521	0.861	0.8	0.0574	0.070	2.6

predicted and observed ès. The Wosten *et al.* (1999) PTF was worst with the largest deviations from zero (ME = 0.1249 cm^3cm^{-3} and RMSE = 0.132 cm^3cm^{-3}). However, all PTFs yielded R^2 values of 2.6%. This validates dissimilarities between the PTF development datasets and the study soils.

The greatest estimation bias was for the n-parameter (ME = -0.659-0.8521) with the Vereecken *et al.* (1989) PTF worst (Highest ME (0.8521) and RMSE (0.861), lowest R^2 value of 0.8%). The Wosten *et al. (1*999) PTF, best predicted the n parameter with ME, RMSE and R^2 values of 0.1515 cm^3cm^{-3}, 0.196 cm^3cm^{-3} and 13.0% respectively. The other PTFs have R^2 values of between 4.7-7.6%, ME (-0.659-0.1852) and RMSE (0.219-670).

For the a-parameter, the Weynants *et al.* (2009) and Zacharias and Wessolek (2007) PTFs yielded the highest R^2 value (10.15% and 6.93% respectively). The Vereecken *et al.*, (1989) PTF showed the worst performance (R^2 = 2.75%, ME = 0.4256 cm^{-1} and RMSE = 0.609 cm^{-1}).

Research Application

To develop better water management strategies, the tested pedotransfer functions offer promise but with recalibration process to improve their utility and bridge the dearth in hydraulic data needed at short temporal and large spatial scales for water balance simulation studies in irrigation and crop production systems.

Recommendation

Great caution is needed before applying these parametric PTFs to tropical soils as prediction uncertainties are evident in the PTFs. Parametric PTFs calibrated on local datasets need to be developed. There should not be a compromise about the accuracy of surrogate data used as PTF inputs, otherwise prediction uncertainties arise.

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