Water retention estimation and plant availability for subtropical Brazilian soils

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Abstract

Limited databases on water retention and availability in soils to generate pedotransfer functions are available for tropical and subtropical soils. The objectives of the study were to generate and evaluate pedotransfer functions for soil water retention in soils from subtropical Brazil; and to estimate plant available water based on soil particle size distribution. Two databases were set up for soil properties including water retention: one had 725 data and the other 253 data. From the literature database, pedotransfer functions were generated, nine pedofunctions available in the literature were evaluated and the plant available water capacity was calculated. Pedotransfer functions for selected sections generated for the soils had coefficients of determination ranging from 0.56 to 0.66. Pedotransfer functions generated with soils from other regions were not appropriate for estimating the water retention. Plant available water content varied with soil texture class, from 0.089 kg kg^{-1} for the sand texture class to 19.6 kg kg^{-1} for the silty clay class. These variations were more dependent on sand and silt content than on clay content. The soils with a greater silt/clay ratio, that were less weathered and had a greater quantity of smectite clay minerals, possessed greater water retention and plant available water capacity.

Key Words

Pedotransfer functions, moisture retention, field capacity, permanent wilting point, tropical soils, ferralsols

Introduction

Plant available water in the soil is essential for adequate development of crops and is dependent on soil properties. To overcome difficulties in water retention and availability determinations, researchers have proposed mathematical models to estimate soil water retention (Saxton *et al*., 2006), known as pedotransfer functions or equations (pedofunctions). These models estimate water retention by means of soil properties that are more easily obtainable or available in the literature, which are related to water retention, and are generally related to capillarity and water adsorption phenomena (Rawls *et al*., 1991).

Models were initially developed for temperate regions, where the edaphoclimatic properties are different from tropical regions, which may make their use for these regions unviable (Tomasella *et al*., 2000). In Brazil, some pedotransfer functions have already been established for estimating soil water retention (Arruda *et al*., 1987; Masutti, 1997; Giarola *et al*., 2002; Oliveira *et al*., 2002), but their validity for other soils different from the database soils has been little studied, which makes one question the degree of efficiency of generalized use of these equations.

The objectives of this study were: to generate pedotransfer functions to estimate soil water retention at different tensions from easily obtainable soil properties; to evaluate the efficiency of pedotransfer functions generated in other regions for the estimation of water retention in subtropical soils from southern Brazil; and to calculate plant available water capacity based on soil particle size distribution of Brazilian subtropical soils.

Methods

The pedotransfer functions for the soils were generated from data obtained from the 25 literature sources. These studies were generated from samples collected from soil classes and horizons which represent various regions of the state, giving a total of 725 sets of data, which include water retention curves, organic matter content, clay, silt and sand, and bulk and particle density.

Retention data was available for up to eight tensions. The water retained at the tension of 10 kPa was denominated as field capacity and that of 1,500 kPa as permanent wilting point. The option was made to standardize the estimation of water retention at 10 kPa, determined in the laboratory, in spite of the concept of field capacity for a given tension being questionable.

Based on the database, multiple regression analyses were made for obtaining the pedofunctions using the stepwise option. This method selects the independent variables, sand, silt, clay, organic matter, bulk density, particle density and the sum of the clay fractions plus silt (soil properties) and generates the respective coefficients that compose each pedofunction to estimate the water content retained by the soil at the tensions of 6, 10, 33, 100, 500 and 1,500 kPa. Pedofunctions to estimate water retention for the tensions of 10, 33 and 1,500 kPa were also generated simply from particle size distribution data, necessary for databases that do not have the organic matter content and the bulk and particle densities.

To evaluate the accuracy of other available equations, those that estimate the gravimetric soil water content were used, such as those proposed by Arruda *et al*. (1987), Oliveira *et al*. (1992), Bell & van Keulen (1995) and Masutti (1997), and others that estimate the volumetric soil water content, such as those from Gupta & Larson (1979), Rawls *et al*. (1982), Saxton *et al*. (1986), Van den Berg *et al*. (1997) and Giarola *et al*. (2002), with data of organic matter, bulk density and clay, silt and sand content. Estimated moisture was correlated with the moisture measured for each model.

Water content at field capacity (10 kPa) and at the permanent wilting point (1,500 kPa) and plant available water capacity (between 10 and 1,500 kPa) were calculated for each sample. The results were grouped by textural class and the mean of each class was presented in a textural triangle. For these properties, regression analysis and path analysis were done. In this analysis, the data were submitted to descriptive statistics, Pearson correlation analysis and multicollinearity. Variables with high and severe multicollinearity were not included in the path analysis.

Results

Soil physical properties and water retention

The clay contents varied from 0.01 to 0.82 kg/kg, silt from 0.01 to 0.78 kg/kg and sand from 0.01 to 0.99 kg/kg. The organic matter content varied from 0.01 to 0.10 kg/kg and the bulk density from 0.86 to 1.85 kg/dm^3. This ample variation is favorable and necessary for the generation of pedotransfer functions (Pachepski & Rawls, 1999). Thus, water retention also varied, as exemplified for the tension of 1,500 kPa, with levels from 0.01 to 0.48 kg/kg. These differences reflect the material of origin and the degree of weathering and thus the physical, chemical and mineralogical properties of the soil.

Water retention had a positive correlation with the clay content, because this fraction favors the occurrence of micropores and menisci, which generate capillary forces. In addition, clay increases the specific surface area of the soil matrix and, consequently, water adsorption. These two phenomena, capillarity and adsorption, determine the matric potential and are responsible for soil water retention.

Estimation of water retention and validation of the pedofunctions

The independent variables included in the equations were the same as the model presented by Gupta & Larson (1979) and Rawls *et al*. (1982), and the coefficient associated with bulk density also had a negative signal, as in that study, which is due to the fact that sandier soils, with low water retention, are denser.

The pedofunctions generated have coefficients of determination (R^2) that vary from 0.56 at the tension of 500 kPa to 0.67 at the tensions of 6 and 10 kPa, all significant at the 1% level. Nevertheless, there are overestimates for low tensions and underestimates for high tensions of water retention, differences expressed in the angular coefficient (slope of the equation), always less than one, with variation from 0.56 to 0.67. The pedofunctions generated only with particle size distribution data had R^2 from 0.44 to 0.54, less than those of the equations that also use organic matter and bulk density, when only the particle size distribution data are available.

Evaluation of pedofunctions from the literature

Of five models tested that of Masutti *et al*. (1997) for the tension of 33 kPa and of Oliveira *et al*. (2002) for the tensions of 33 and 1,500 kPa were those that resulted in the best estimation of water retention, in spite of underestimating water retention for greater tensions. The model from Arruda *et al*. (1987) presents a gravimetric soil water content estimated at approximately 0.32 kg/kg at the tension of 33 kPa, while the measured contents are much higher than this level. All the models underestimate water retention for high tensions, which may be observed by the b coefficient of the determined equation, which frequently has a value of less than 0.5. The model from Bell and van Keulen (1995) estimated with greater precision the retention measured for the soils of Rio Grande do Sul. Nevertheless, the b coefficient of the equation was 0.61, different than 1 from the straight line 1:1. This indicates that for low tensions there was an underestimation of water retention.

Models developed from soils of the temperate climate region, such as those from Gupta & Larson (1979), Rawls *et al*. (1982) and Saxton *et al*. (1986), also had under or overestimation in water retention; nevertheless, variability was high. With the exception of the model from Saxton *et al*. (1986) for the tension of 33 kPa, the other models had R^2 less than the models developed from the soils of tropical regions. This may be due to differences in mineralogy between the soils of the tropical regions and the temperate climate regions.

To evaluate the accuracy of the model proposed, the estimated results were compared with those estimated by the models from Oliveira *et al*. (1992) and from Masutti (1997), which were generated with data from the State of Pernambuco. The water retention estimation from the proposed model, compared to that estimated by the model from Oliveira *et al*. (1992) has a higher R^2 (0.93 for 33 kPa to 0.92 for 1,500 kPa), but the model proposed overestimates water retention at the tension of 1,500 kPa. For the Masutti (1997) model, the R^2 were 0.46 for 33 kPa and 0.94 for 1,500 kPa. In addition, the angular coefficient at the tension of 1,500 kPa was only 0.42, very different from the unit value, which indicates a significant underestimation.

With the objective of making equations available when there is only information regarding particle size distribution, three water retention equations were generated for the tensions of 10, 33 and 1,500 kPa. For the tensions of 33 and 1,500 kPa, it was possible to evaluate the equations with the data available for soils from an irrigation system. It may be seen that at the tension of 33 kPa, the R^2 between the estimated moisture and the measured moisture was 0.73, while for 1,500 kPa it was 0.76.

Plant available water

Through path analysis, the direct and indirect effects of soil properties on water retention were evaluated. For water retention at field capacity (10 kPa), direct and positive effects are seen from clay and silt, and a negative effect from bulk density. The direct effect of clay (R=0.71) is greater than its total effect (R = 0.62) due to its indirect effect through silt content (R = -0.23). In the more clayey soils, the silt content had a negative relationship with clay (R = -0.42) and the lower direct contribution from the silt fraction to water retention (R=0.54) diminishes the total effect from the clay in that retention.

The total effect of bulk density was negative (R = -0.65), a result of its direct effect (R = -0.27) and indirect effect via the clay content (R = -0.34). In denser soils, the volume of larger pores diminishes, affecting water retention at field capacity. With an increase in sand content, bulk density increased (R = 0.51); thus in the denser and sandier soils, water retention was less, which resulted in an indirect effect from particle size distribution in reduction of field capacity in the denser soils. The organic matter content had a total positive effect on water retention at field capacity, with a correlation coefficient of 0.41. Nevertheless, the direct effect was low (R = 0.14), while the indirect effect through clay (R = 0.04), silt (R = 0.15) and bulk density (R = 0.09) were responsible for the total effect.

Similar effects to those discussed for field capacity were observed for the permanent wilting point, however with different correlation coefficients, primarily by the lower direct effect from the silt fraction. Furthermore, for bulk density, the negative effect on water retention (R = -0.44) was principally indirect via clay content (R = -0.33) and from organic matter (R = -0.04).

The water content retained at field capacity varied from 0.141 kg/kg in the sand class to 0.477 kg/kg in the silty clay class, while the permanent wilting point varied from 0.050 kg/kg in the sandy loam textural class to 0.286 kg/kg in the silty clay textural class. Both the field capacity and the permanent wilting point increased in similar magnitude with the increase in clay content, which caused the plant available water capacity to change little with the increase of clay content in the soil.

The mean plant available water capacity for the soils evaluated was 0.130 kg/kg, with less retention in the sand textural class and greater in the silt-clay textural class (Figure 1). Other classes with greater retention were silty clay loam (0.158 kg/kg) and the silty loam (0.176 kg/kg). In the other textural classes, the plant available water capacity varied little with the particle size distribution, from 0.116 kg/kg, in sandy clay loam, to 0.137 kg/kg, in sandy clay soil. The lower plant available water capacity in the sand textural class is related to the low specific surface area of these soils, while the greater availability in the silt-clay class is related to the greater presence of clay and silt, with a greater specific surface area. When the three classes with greater retention are examined, it is observed that these soils are less weathered and with a greater silt clay ratio and, thus, greater contribution to water retention by 2:1 type minerals.

The path analysis showed that the plant available water capacity had positive total correlation with the silt content (R = 0.22) and organic matter (R = 0.19), and negative with bulk density (R = - 0.30). For the silt content and bulk density, the effects were direct, while for organic matter, the direct effect was small (R = 0.04) and the total effect was dependent on the indirect effects via the silt content (R = 0.06) and bulk density (R = 0.10). Soils with greater organic matter content were those with greater silt content (R = 0.22); thus, the greater water retention of these soils was also via silt. Low correlation coefficients among soil properties and plant available water capacity have frequently been related (van den Berg *et al*., 1997; Giarola *et al*., 2002), probably due to the interactions with positive and negative effects among the soil properties, which could be verified through path analysis.

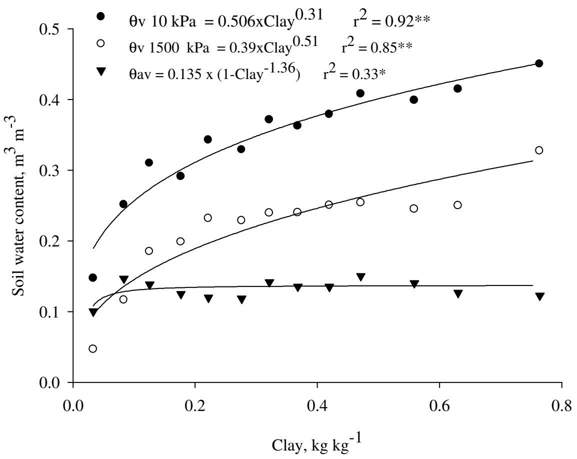

Figure 1. Relationship between clay content and moisture at field capacity (UV 10 kPa), permanent wilting point (UV 1500 kPa) and available water (UV10 - UV 1500 kPa) for the subtropical soils.

Conclusion

Pedotransfer functions generated from soils from other geographical regions were not adequate for estimating water retention for the soils of southern Brazil and, for the soils evaluated, the proposed equations generally included the variables of organic matter, bulk density and the sum of the clay plus silt fractions. The contents of clay, silt and organic matter had total positive correlation with soil water content at field capacity and at permanent wilting point, whereas bulk density had negative correlation with water content in field capacity. Part of the correlation was due to an indirect effect, as a consequence of interrelationships which exist among soil properties.

The lowest level of plant available water capacity was in the sand textural class due to the low specific superficial area, while the greatest level was observed in the classes with a greater silt content and, therefore in those with a greater silt/clay ratio, indicative of less weathered soils with a greater quantity of 2:1 type clay minerals.

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