Modelling thermal diffusivity of sandy soils

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Thermal diffusivity ($\kappa$) of soils is highly dependent on soil moisture ($\theta$), and so it is a common practice to measure the thermal diffusivity across a range of water contents. Thermal diffusivity of sandy soils, which occupy about 10% of land surface, was investigated. The results of this research may be used in various studies for sandy soils energy and water balance calculation. This study aims at the regression model of the sandy soils $\kappa(\theta)$ curves introduction. To achieve this goal, 9 more samples of sandy soils of the East European Plain were taken. Undisturbed soil cores were sampled from the 0–1.75 m layer with thin-walled steel cylinders 70 mm in height and 50 mm in diameter and were studied using the unsteady-state method. Additional sampling was carried out to provide soil material necessary to investigate basic properties of soils. Statistic analysis was performed for the dataset of 23 samples including the newly studied Lammelic Arenosols from Voronezh region and earlier investigated Anthrosols, Brunic Arenosols, and Albic Retisols from Moscow region. The ranges of sand, silt, and clay within the data set were 87–97, 0–8, and 1–6%; organic carbon content ranged from 0.1 to 0.9%; bulk density was rather high: from 1510 to 1660 kg m$^{-3}$; Thermal diffusivity of capillary moistened soils was $(6.2–7.6)\times10^{-7}$ m$^2$s$^{-1}$; that of air-dry soils was about $2\times10^{-7}$ m$^2$s$^{-1}$, and the peak values were almost $10\times10^{-7}$ m$^2$s$^{-1}$ for soils with organic carbon content less than 0.3%, and did not exceed $8.5\times10^{-7}$ m$^2$s$^{-1}$ for soils with organic carbon content from 0.5 to 0.9%. To compare different $\kappa(\theta)$ curves, we used a four-parameter approximation:

$$\kappa = \kappa_0 + a \exp \left[ -0.5 \left( \frac{\ln(\theta/\theta_0)}{b} \right)^2 \right]$$

where $\kappa_0$ is the thermal diffusivity of dry soil, $\theta^*$ is the difference between the highest thermal diffusivity and the thermal diffusivity of dry soil, $\theta_0$ and $b$ are shape parameters. The Willmott index of agreement between the model-predicted and observed values ($d_\theta$), which approaches 1.0 when the predictions approach the observations, was used for evaluating the approximation quality. The efficiency of grouping soils was confirmed. The average curves for two groups differing in organic carbon ranges ($C \geq 0.5\%, \ d_\theta = 0.877$; $C < 0.5\%, \ d_\theta = 0.819$) turned out to be more precise than the average curve obtained for the whole dataset ($d_\theta = 0.796$). The linear correlation
analysis of soil properties and the parameters of $\kappa(\theta)$ curves revealed a correlation between organic carbon content and $D^0$ (-0.623) and between bulk density and $\kappa_0$ (0.574). Curve parameters and basic soil properties of samples were used in order to carry out the forward stepwise multiple regression. The quality of obtained regression functions was evaluated using the $R^2$ coefficient. The higher $R^2$ values of $\kappa_0$ and $a$ were 0.776 and 0.637, respectively; the lower $R^2$ values of $\theta_0$ and $b$ were 0.485 and 0.451, respectively. The obtained regression functions allow estimating apparent thermal diffusivity of sandy soils basing on available data on basic soil properties and soil water contents.