Thermal diffusivity of sands as related to soil moisture: direct measurements and model estimates

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Introduction

Sandy soils are widely spread across the world. They may be found in the widest possible range of climates, from very arid to very humid and from cold to hot. All in all, they occupy about 1 300 million ha or 10% of land surface.

The temperature dynamics in soil profile depends on thermal diffusivity. The above-mentioned thermal diffusivity is responsible for the rate of soil heating and cooling.

$$\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial z^2}$$

Thermal diffusivity → $\kappa = \frac{\lambda}{c_v}$ (λ ← Thermal conductivity; c_v ← Heat capacity)

In order to estimate thermal diffusivity of different sandy soils, regression equations to calculate the parameters of water content–thermal diffusivity curves from soil properties were obtained.
The parameterization of water content–thermal diffusivity curves was used since the thermal properties of sandy soils are highly dependent on soil moisture.

Objects and methods

Location of the sampling sites.
Map data ©2019 Google.

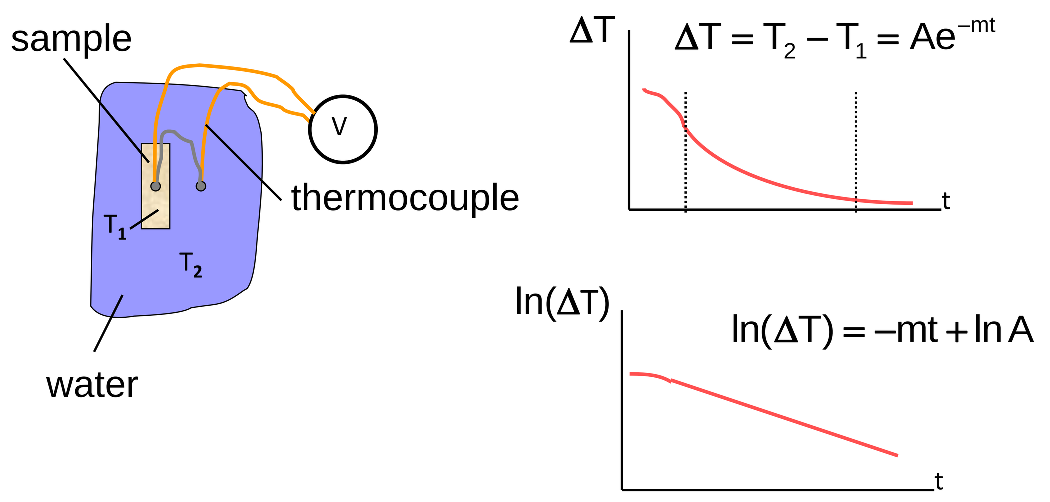
The research targeted at Lammelic Arenosols sampled in the southeastern part of the Voronezh Region in the Bobrovsky district (51°10'N, 40°18'E).

Lammelic Arenosols were studied at three plots in the 'Khrenovsky Bor' area that is the natural reserve of the Bobrovsky district. This natural reserve has some specific features among which are dune relief and pine forest. So, the plots 1 and 2 were located on the slopes of a sand dune and the plot 3 was located at the top of the dune.

All the plots included buried layers with relatively high organic carbon content and were underlain by loess loam.

The unsteady-state method

Thermal diffusivity of peat-sand mixtures was determined in laboratory using the unsteady-state method. Cylindrical measuring cells with a height of 10 cm and a diameter of 4 cm were used. Soil thermal diffusivity at certain moisture content was determined from the heating curve of peat-sand sample packed in the waterproof measuring cell and placed into a water bath with a constant temperature which was higher than the initial temperature of the sample. The heating rate was considered to be proportional to the thermal diffusivity of the sample.

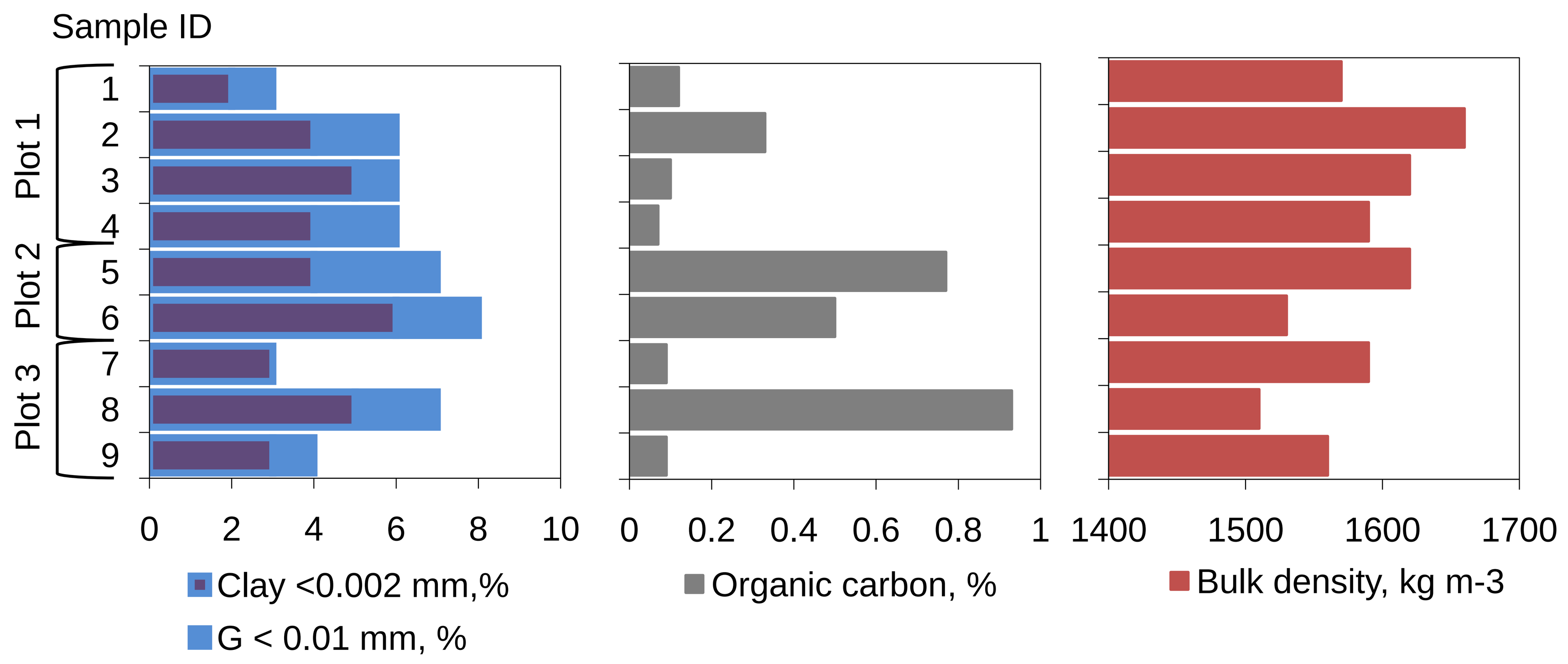


Heating rate: $m = kB$

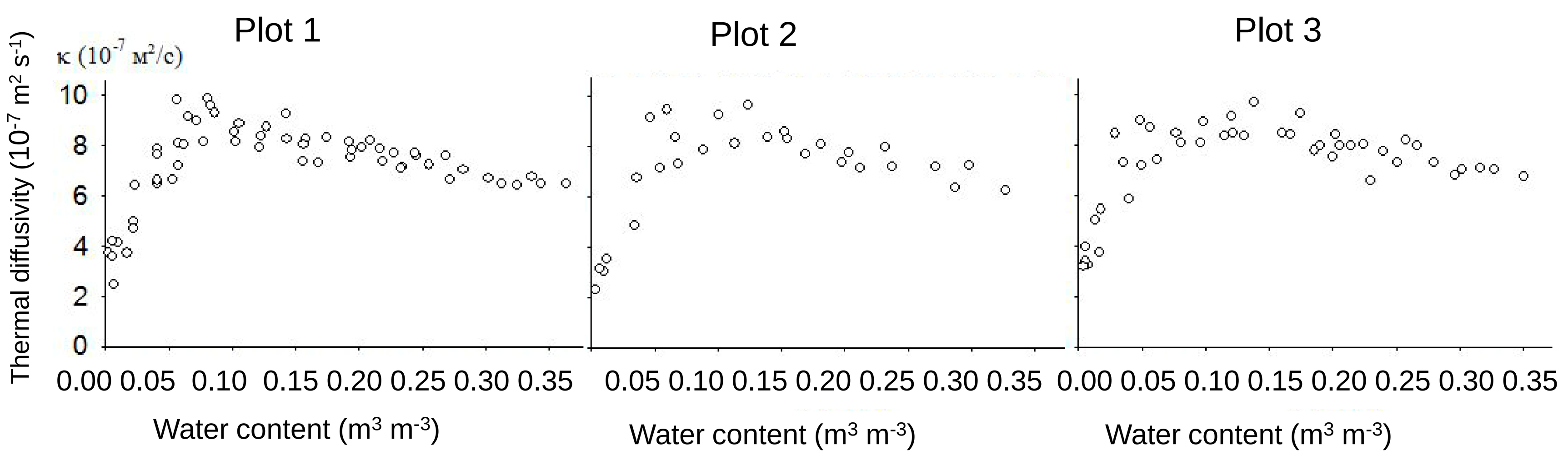
$$B = \frac{1}{\left(\frac{2.4048}{r}\right)^2 + \left(\frac{\pi}{h}\right)^2}$$

Results

Properties of studied materials



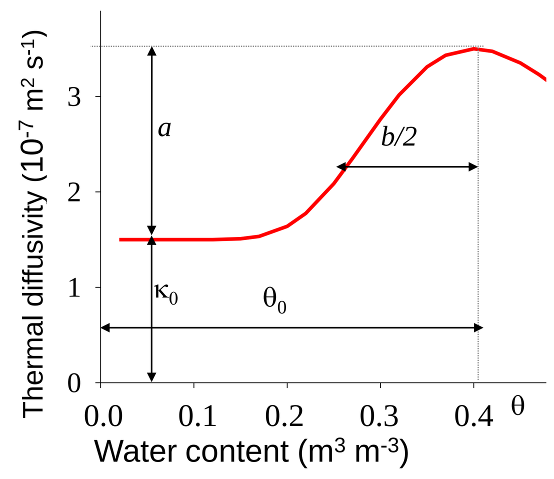
Water content–thermal diffusivity data



Parameterization of water content–thermal diffusivity curves

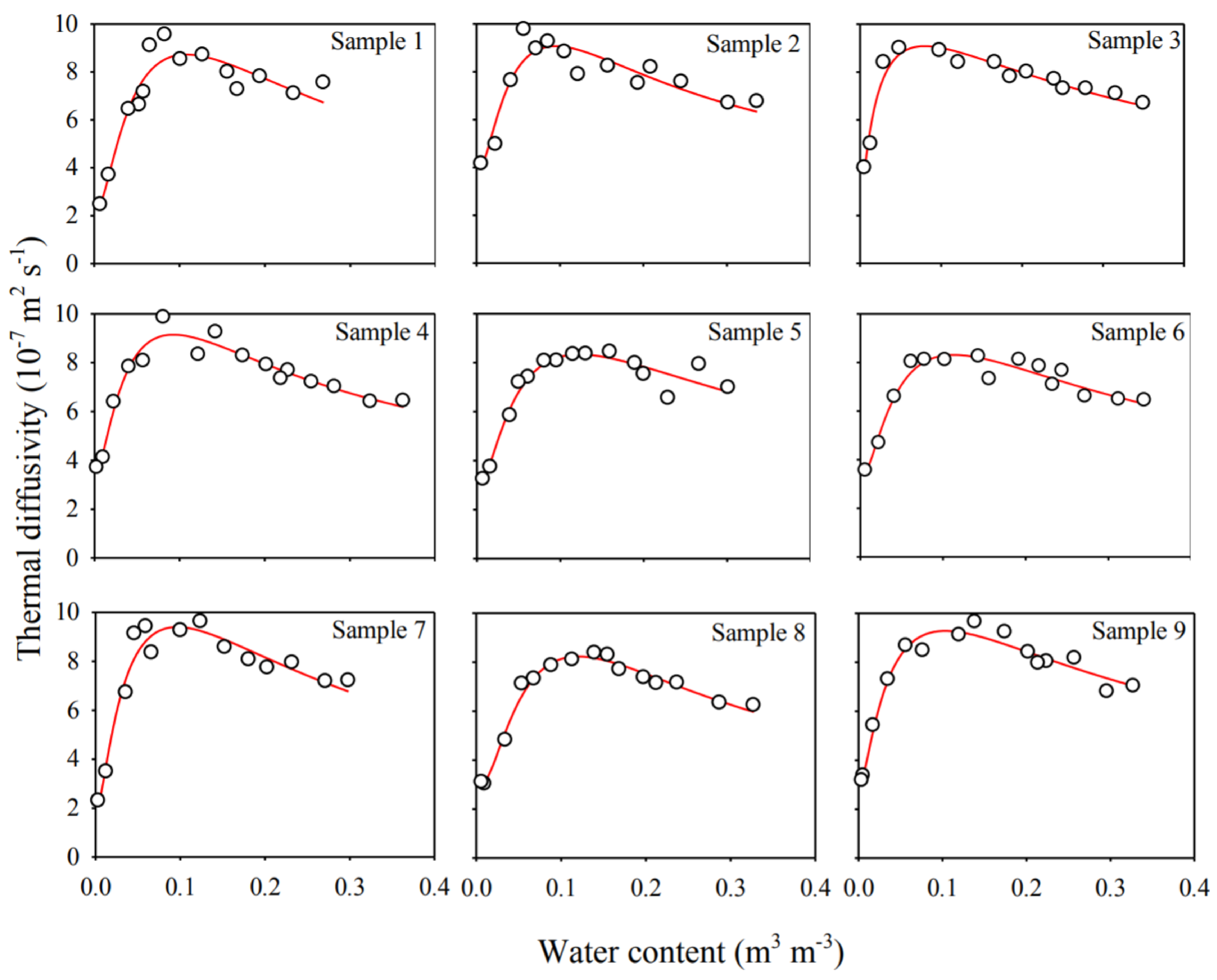
To compare different curves and to analyze them formally, we used a four-parameter approximation. The suggested approximation has an advantage of clear physical interpretation: its parameters are (1) the thermal diffusivity of the dry sample; (2) the difference between the highest thermal diffusivity at some optional water content and that of the dry sample; (3) the optional water content at which the thermal diffusivity reaches its maximum; (4) and the half-width of the peak of the curve.

The next step was to obtain regression equations to estimate the parameters of water content–thermal diffusivity curves from clay content, particles of size (< 0.01, mm) content, bulk density and organic carbon.



$$\kappa = \kappa_0 + a\exp\left[-0.5\left(\frac{\ln\left(\frac{\theta}{\theta_0}\right)}{b}\right)^2\right] \quad (1)$$

Parameters of κ(q) curves



In order to make regression model, additional data of 17 sandy samples (κ(q) curves parameters and soil properties) from (Arkhangelskaya T and Lukyashchenko K, 2018) was used.

Estimating procedure

Clay (< 0.002 mm) (S), G (< 0.01 mm) (G), bulk density (ρ_b), carbon content (C) →

$$a = (17.11 - 2.916 \times (C) - 6.643 \times (\rho_b)) \times 10^{-7}$$

$$\kappa_0 = (0.2415 \times (G) - 0.5510 \times (C) + 2.254 \times (\rho_b) - 1.807) \times 10^{-7}$$

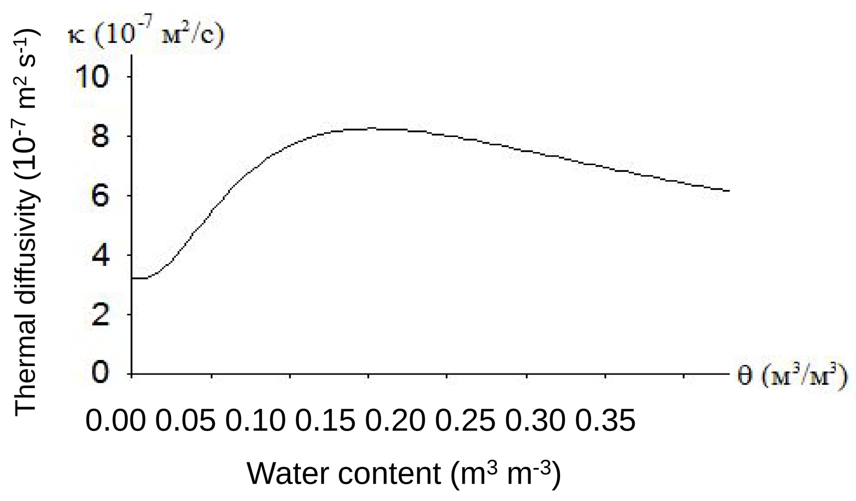
$$\theta_0 = 0.1869 + 0.07275 \times (C) - 0.02344 \times (S)$$

$$b = 1.184 - 0.09496 \times (G) - 0.1163 \times (S)$$

↓ κ_0, a, b, θ_0

moisture content (q) → $\kappa = \kappa_0 + a\exp\left[-0.5\left(\frac{\ln\left(\frac{\theta}{\theta_0}\right)}{b}\right)^2\right]$ → thermal diffusivity (k)

Example



Parameters:

P_b = 1600 kg m^{-3}
C = 0.5%
S = 6%
G = 7%

Acknowledgement

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