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KamelSoil®: A model for soil characterization from basic soil textural properties

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Abstract. *A new conceptual and functional model of the soil-water medium organization, in which the internal structure of the soil horizon, named the pedostructure, is made up of swelling aggregates in a hierarchy of sizes, was recently presented. This representation leads to define a new paradigm for modeling the physical interaction between the soil structure and the water at the level of the process and for the macroscopic characterization of soil physical properties at the field scale. A computer model of the hydro-structural functioning of a pedon, named Kamel®, was built in the framework of this paradigm. Accordingly, the hydrostructural input parameters of Kamel® are those of* *physically-based equations that describe the hydraulic functionality of the pedostructure, namely: 1) the shrinkage curve, 2) the soil water potential curve, 3) the conductivity curve, and 4) the swelling dynamic curve. These parameters have a physical meaning and can be extracted precisely from the measurement of the characteristic curves in laboratory. The objective of the paper is i) to present the basic principles of Kamel® along with the state variables and functional parameters used, allowing to calculate the state variables at each depth of the pedon and to integrate this information at the field scale level; and ii) to present "KamelSoil®", a software that translates the traditional soil characteristics into the required hydrostructural parameters of Kamel®. Therefore Kamel® can theoretically work for all soil types, at high degree of accuracy when the characteristic curves are measured or, at least, with the same approximations made by the usual soil-water models using empirical parameters and pedotransfer functions.*

Keywords. Soil water interaction, pedostructure, Kamel® Model, shrinkage curve, potential curve, pedotransfer function.

Introduction

Soil water models describe soil properties independently from the aggregated organization of soils and their hydro-structural dynamic. This leads to an empirical approach of representing and estimating the physical properties currently used in these models, such as water potential, field capacity, available water, air capacity, hydraulic conductivity etc. (Braudeau and Mohtar, 2004a, Braudeau et al. 2005). Additionally, since the characteristics of the soil organization are not defined, modelling the biophysical and chemical possesses in the soil medium cannot be physically based on a specific soil organization and thus, to a particular type of soil.

Braudeau et al. (2004b) presented a new conceptual and functional model of the soil-water medium organization where the internal structure of the soil horizon is made up of swelling aggregates in a hierarchy of sizes. This representation leads Braudeau and Mohtar (2007) to define a new paradigm for taking account of the soil structure and water interaction in the soil-water modelling and for being able to characterize the soil physical properties at the different functional scales of the structure.

A computer model of the hydro-structural functioning of a pedon, named Kamel®, was built in the framework of this paradigm. Accordingly, the hydrostructural input parameters of Kamel® are those of physically-based equations that describe the hydraulic functionality of the pedostructure, namely: 1) the shrinkage curve, 2) the soil water potential curve, 3) the conductivity curve, and 4) the swelling dynamic curve. These parameters have a physical meaning and can be extracted precisely from the measurement of the characteristic curves in laboratory. The objective of the paper is i) to present the basic principles of Kamel® along with the state variables and functional parameters used, allowing to calculate the state variables at each depth of the pedon and to integrate this information at the field scale level; and ii) to present "KamelSoil®", a software that translates the traditional soil characteristics into the required hydrostructural parameters of Kamel®.

Basic principles of the new soil-water computer model Kamel®

Kamel® is based on four principles or notions that are introduced in soil physics for taking account of the hierarchical internal organization of the soil medium, lieu of biological and geochemical processes.

Using both notions of REV and SRV of the soil medium for the transfer of scale

Braudeau and Mohtar (2007) present the new notion of "Structure Representative Volume" (SRV) as follows: Similar to the well know "Representative Elementary Volume" (REV) used in soil physics and hydrology in order to apply equations of the continuous porous media theory, a SRV represents a homogeneous medium and do not have any physical boundary; but unlike REV, SRV is virtually delimited by an enclosure which is permeable to air, water, or salts fluxes but not to solids that compose the structure. This description defines any SRV as a volume V comprised of a fixed mass of solids, m_s, such that its specific volume, defined as $\overline{V} = V/m_S$, depends only on the change in content of its mobile phases. That gives to SRVs the following properties:

- A given SRV encloses a constant structural mass, m_s, and its descriptive variables refer to this structural mass instead of the volume. This mass corresponds to the classical oven dried mass of the sample at 105°C.

- The SRV delineation is linked to the structured solid phase. Once defined or recognized, it is positioned in the 3-D space relative to the spatial organization of the medium of which it belongs. Adding solids into a SRV, and thus increasing the structural mass (m_S) independent of the structural volume, is not allowed because such operation should change the structure of the SRV and its hydrostructural properties. The only possible change of m_s without any changes to the structure and hydrostructural properties would consist of a change of delineation within the same structured medium.

Organizational variables of an SRV can be nested with respect to the hierarchical organization of the medium. Relationships between these variables at different levels of scale can be established in regard to the organization and functionality of the SRV. An example is given by the organizational variables of the pedostructure which was defined by Braudeau et al. (2004a) as the SRV of the soil fabric in a soil horizon presented in Table 1.

Kamel® uses the specific SRV variables (like W and $\overline{V}$) for modelling **all processes at their local scale in the soil medium** and the volumetric REV variables (like θ, ratio to a soil volume that is not linked to the structure) for providing as outputs integrated soil variables at the macroscopic field level. In fact, REV variables are macroscopic mean variables and should not be used for describing processes at their local scale of emergence (Braudeau and Mohtar, 2007).

The notion of primary ped

Brewer (1964) introduced the following concepts of *primary ped* and *S-matrix*:

“A ped is an individual natural soil aggregate consisting of a cluster of primary particles and separated from adjoining peds by surfaces of weakness which are recognizable as natural voids or by occurrence of cutans.”

“Primary peds are thus the simplest peds occurring in a soil material. They cannot be divided into smaller peds, but they may be packed together to form compound peds of higher level of organization. The S-matrix of a soil material is the material within the simplest (primary) peds, or composing apedal soil materials, in which the pedological features occur; it consists of plasma, skeleton grains, and voids that do not occur in pedological features other than plasma separations.”

“It is apparent from the definitions of the levels of structure and from the nature of soil materials that structure analysis is concerned with units with very different hydraulic properties: plasma, skeleton grains, peds, voids...”

Braudeau et al. (2004) complete this morphological definition with a functional definition based on the determination of the air entry point of the S-matrix on the continuously measured shrinkage curve (Braudeau and Bruand, 1993). This definition allowed the physical characterization of its behavior, inside of the pedostructure, in interaction with the soil water (Braudeau et al., 2004). It allowed also obtaining the primary peds of a soil sample in laboratory using the soil fractionation method of Colleuille and Braudeau (1996).

Therefore variables and parameters are defined for both distinct media of the pedostructure: inside and outside of the primary peds: V_{mi}, Vp_{mi}, W_{mi}, h_{mi}, k_{mi}, Vp_{ma}, W_{ma}, h_{ma}, k_{ma} (see the nomenclature and definition in Table 1 and Appendix).

Table 1: Name and symbol used for the state variables in the pedostructure at its different levels of organization

Volume of concern	***Specific volume***	***Specific pore volume***	***Water content***	***Non swelling water***	***Swelling water***	***Suction pressure***
Pedostructure	V		W			h
Interpedal porosity		Vp_{ma}	W_{ma}	w_{st}	w_{ip}	h_{ma}
Primary peds	V_{mi}	Vp_{mi}	W_{mi}	w_{re}	w_{bs}	h_{mi}
Primary soil particles	V_s					

The four types of water pools in the structured soil medium

For interpreting the shrinkage curve (SC) Braudeau et al. (2004a) define two pools of water in the two pore systems, inside and outside primary peds: swelling water, w_{sw}, and condensed water or non swelling, w_{cn}. Swelling water occupies a pore space acquired by the spacing of particles or aggregates under the effect of osmotic pressure. Its removal from the sample causes shrinkage of the concerned pore system. Condensed water, on the other hand, occupies an interstitial pore space and is replaced by air (or water vapor at saturation pressure) when it leaves the pore; its loss causes little or no shrinkage. During drying, each linear phase of the shrinkage curve is caused by the predominant departure of **only one pool of water**, w_{sw} or w_{cn}, from either the micro- or the macro-pore system (Fig. 1). In general there are four water pools that evaporate successively from a soil sample initially saturated: they were called in reference to the corresponding shrinkage phase, interpedal, structural, basic and residual: w_{ip}, w_{st}, w_{bs}, w_{re}.

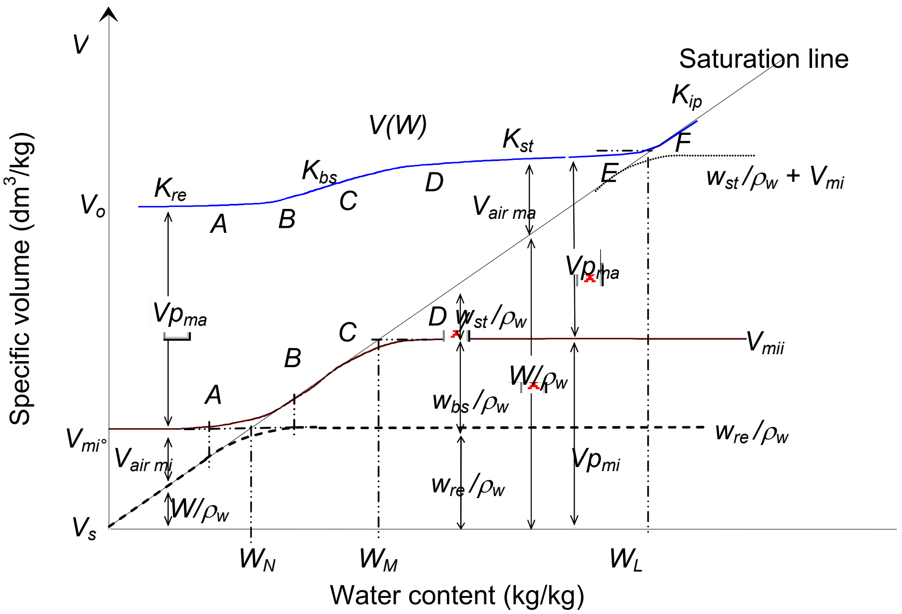

Figure 1. Graphical representation of the specific volumes of the pedostructure (V, in blue) and primary peds (V_{mi}, in brown), the specific pore volumes (Vp_{mi} and Vp_{ma}), the air contents (V_{airmi} and V_{airma}) and the water pools (W, w_{re}, w_{bs}, w_{st}, and w_{ip}) of the pedostructure starting from a measured SC. V_{mi} is equal to ($Vp_{mi} + V_s$) = (max(w_{re}) + w_{bs} + V_s) .

The soil water potential

The usual approach for modeling soil water potential emphasizes the geometrical aspect of the structure, restricting the matric water potential to the interfacial tension of the air-water meniscus in a capillary. Its curvature determines the potential according to Laplace-Kelvin's law and is assimilated to the pore radius r_c for which all pore segments with sides shorter than $2r_c$ are filled with water. This approach does not make reference to any swelling pressure, due to osmotic or hydration force of interaction between solid surfaces and water.

Braudeau and Mohtar (2004a) showed that, in contrast to the usual approach, the physico-chemical approach of Low (1987), Voronin (1980) and Berezin (1983) calls for other notions than the interfacial meniscus curvature. According to Low (1987), water is arranged in layers at the surface of the particles and a swelling pressure is observed depending on the thickness of the water film (τ) and the specific surface area of the soil particles. In this approach, the thickness t of the film of water at the surface of the unsaturated pores is used as the variable. The difference with the Laplace-Kelvin approach is that the change of water is simply related to τ by $dW = S d\tau$ where S is the specific surface area of the solids. The geometry of the structure is less important in this approach than the knowledge of the nested organization up into swelling aggregates which defines different levels of surface area (for example the surfaces outside, relatively to inside, of the primary peds).

Equations of the equilibrium state of the soil medium

Water pools in the pedostructure at equilibrium

At equilibrium at given water content W, equations of the water pools in term of the total water content W are, according to Braudeau et al. 2004:

$$w_{ip}^{eq} = \frac{1}{k_L} \ln\left[1 + \exp\left(k_L\left(W - W_L\right)\right)\right] \tag{1}$$

$$w_{st}^{eq} = -\frac{1}{k_M} \ln\left[1 + \exp\left(-k_M\left(W - W_M\right)\right)\right] - w_{ip}^{eq} \tag{2}$$

$$w_{bs}^{eq} = \frac{1}{k_N} \ln\left[1 + \exp\left(k_N\left(W - W_N\right)\right)\right] + \frac{1}{k_M} \ln(1 + \exp\left(-k_M\left(W - W_M\right)\right)) \;; \tag{3}$$

$$w_{re}^{eq} = -\frac{1}{k_N} \ln\left[1 + \exp\left(k_N\left(W - W_N\right)\right)\right] + W \tag{4}$$

Parameters W_N, W_M, W_L are the water content at the intersection points N', M', L' of the tangent lines extending the quasi-linear shrinkage regions of the shrinkage curve (Figure 1). Their value represents characteristic pore volumes of the pedostructure with ρ_w being the water density in kg dm^{-3}:

$W_N = \max(w_{re}) = \rho_w \min(Vp_{mi})$, the pore specific volume of primary peds at dry state (5)

$W_M = \max(w_{re}) + \max(w_{bs}) = \rho_w \max(Vp_{mi})$, the maximum pore specific volume of saturated primary peds; and

$W_L - W_M = \max(w_{st}) \approx \rho_w Vp_{ip}$, the interpedal pore specific volume in the structural linear region of the shrinkage curve (D-E).

Parameters k_N, k_M, and k_L represent the y-distance between these intersection points and the shrinkage curve (as for example: $k_M/\text{Log}2 = (K_{bs}-K_{st})/(V_M-V_{M'})$). They are constants under experimental conditions, but they depend on the load and overburden pressure under field conditions.

Knowing these water pools contents, the pedostructure variables of state are determined. However, the overburden pressure on a pedostructure unit in the soil in situ was not taken into account yet in Kamel®. The shrinkage curve in situ is considered identical to the measured curve in laboratory without constraint. The dependency of the overburden effect on the ShC parameters with depth and water content is actually investigated (Braudeau and Mohtar, 2004)

The specific volume of the pedostructure is:

$$\overline{V} = K_{\text{bs}} dw_{\text{bs}} + K_{\text{ip}} dw_{\text{ip}} \qquad (6)$$

where K_{bs} and K_{ip} = 1 dm^3/kg are the slopes of the linear basic and interpedal shrinkage phases (parallel to the saturation line), respectively (see Figure 1). They represent the pedostructure volume change caused by the change of the *swelling* water pools w_{bs} and w_{ip}. The slopes are considered as structural parameters of the pedostructure, linking the macroscopic assembly level to the water pools levels. As an example:

$$K_{bs} = \partial\overline{V}/\partial w_{bs} = \partial\overline{V}/\partial\overline{V}_{mi} \qquad (6)$$

where $\overline{V}_{mi}$ is the specific volume of primary peds, including primary particles $\overline{V}_s$:

$$\overline{V} = \overline{V}_{mi} + \overline{V}p_{ma} \text{ and } \overline{V}_{mi} = \overline{V}p_{mi} + \overline{V}_s \qquad (7)$$

Soil water potential

The water suction pressure intra and extra primary peds, h_{mi} and h_{ma}, are expressed according to Braudeau and Mohtar (2004a) in terms of W_{mi} and W_{ma} such as:

$$h_{ma} = Ps_{ma} - Ps^o_{ma} = \rho_w E_{ma}\left(1/(W_{ma}+\sigma) - 1/(W_L - W_M + \sigma)\right) \qquad (8)$$

$$h_{mi} = Ps_{mi} - Ps^o_{mi} = \rho_w E_{mi}\left(1/(W_{mi}-W_N) - 1/(W_M - W_N)\right) \qquad (9)$$

where ρ_w is the water bulk density; Ps_{mi} and Ps_{ma} are the swelling pressure inside and outside the primary peds (Fig. 2), E_{mi} and E_{ma} are the potential energies of the solid phase resulting from the external surface charge of clay particles, inside and outside the primary peds, in joules/kg of solids; σ is a part of the micropore water at interface with interpedal water. Both terms $Ps_{mi°}$ and $Ps_{ma°}$ represent the swelling pressure at saturation, inside and outside of the primary peds, respectively, when $W_{ma} = W_{sat}-W_M$; and $W_{mi} = \max(W_{mi}) = W_M$.

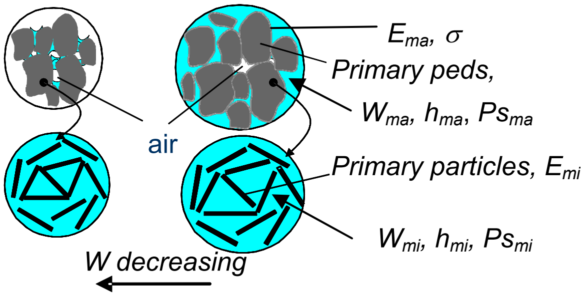

Figure 2. Representation of the variables of state in the pedostructure

Dynamics of the pedostructure

The two opposite dynamics, swelling and shrinking, are supposed to be governed by the same conceptual process that is the water exchange between the primary peds and the interped pore space. Braudeau and Mohtar (2006) validated in a particular case (aggregates immersed in water) the following equation where the water exchange between the two media is proportional to the difference in their suction pressure:

$$\frac{dW_{mi}}{dt} = k_{\mathrm{mi}}\left(h_{\mathrm{mi}} - h_{\mathrm{m}a}\right) \tag{10}$$

In this equation, k_{mi} is the transfer rate coefficient ($\mathrm{kg_{micro\ water}\ kg^{-1}_{soil}\ Pa^{-1}s^{-1}}$) for the absorption-desorption of the interped water by the primary peds. This coefficient expresses the velocity of the last layer of water on the surface of the clay particles entering or leaving the primary peds. This transfer rate coefficient k_{mi} is assumed to be constant, in the considered range of water content ($W_{\mathrm{B}} – W_{\mathrm{L}}$) and that Equation 10 can be generalized to the swelling ($dw_{\mathrm{bs}}/dt > 0$) as well as the shrinkage ($dw_{\mathrm{bs}}/dt < 0$). Braudeau and Mohtar (2006) showed that the micro-macro water exchange, k_{mi}, can be calculated by

$$k_{\mathrm{mi}} = \frac{\left(W_{\mathrm{M}} - W_{\mathrm{N}}\right)^2}{\rho_{\mathrm{w}} E_{\mathrm{mi}}} \frac{0.1931}{t_{1/2}} \tag{11}$$

where $t_{1/2}$ is the time of half swelling in seconds at $w_{\mathrm{bs}} = \max(w_{\mathrm{bs}})/2 = (W_{\mathrm{M}} - W_{\mathrm{N}})/2$. This time of half swelling seems to be a characteristic of the kind of clay in the soil and is easily determined in laboratory using the measurement of the swelling in time of aggregates immersed in water.

Dynamic of water in the inter-aggregate space

Kamel® distinguishes two types of transport: (1) a local transport within the pedostructure (SRV of the horizon), corresponding to a water exchange between the both pore spaces, inside and outside primary peds, and (2) a transport through the SRV that concerns only the interped water. W_{ma} becomes (Braudeau and Mohtar, 2007):

$$\frac{dW_{ma}}{dt} = \rho_w \overline{V}_{layer}\, \frac{d}{dz}\left(k_{ma}\left(-\frac{dh_{ma}}{dz}\right) + 1\right) - \frac{dW_{mi}}{dt} \tag{12}$$

where $\overline{V}_{layer}$ is the specific volume of the thin layer that is considered as a SRV (of which all variables have the same unique value everywhere in the SRV).

Braudeau and Mohtar (2007) showed that, according to the literature, one can assume that the conductivity curve is an exponential function of W_{ma} for the high and low ranges of W_{ma} with parameters of the exponential function different for the two ranges of moisture content. Keeping the distinction between both ranges of conductivities defined by the shrinkage curve (W_{sat} to W_M and W_M to W_C) the two exponential equations were combined in the same logistic equation such that:

$$k_{ma} = \frac{k_{maM}\, \exp\left(\alpha_o W_{ma}\right)}{k_{maM} \big/ k^{o}_{ma} + \exp\left((\alpha_o - \alpha_M) W_{ma}\right)} \tag{13}$$

This equation represents the conductivity curve for the pedostructure model and has four parameters: k_{maM}, α_M, $k_{ma^{\circ}}$, and α_o that can be measured in the laboratory or estimated with pedotransfer functions.

KamelSoil®: Estimation of Kamel® parameters using classical soil data

A complete soil physical characterization requires the measurement in laboratory of the 4 characteristic curves mentioned above: shrinkage curve, water potential curve, conductivity curve and the time dependant swelling curve.

We have few possible cases of using KamelSoil® depending on the availability of the soil data. Two successive steps are considered in the Kamel® parameters estimation:

1st, estimation of the hydrostructural soil parameters provided by both equations of state of the pedostructure: the shrinkage curve and the potential curve, and

2nd, estimation of the dynamical parameters: of the hydraulic conductivity inter-aggregates (k_{maM}, $k_{ma°}$, α_M and $\alpha°$); and of the swelling of the clayey plasma: k_{mi}

I- Hydro-structural state parameters

They are all provided by the shrinkage curve and the water potential curve, from saturation up to the dry state. Concerning the water potential measurement, the methods of reference in laboratory that will be considered valid are the tensiometer method from saturation to 60 kPa and the Richards apparatus for suctions of 100 kPa and more.

There are three cases: 1) the shrinkage curve and the potential curve have been measured 2) only the tensiometric curve has been measured and 3) neither the shrinkage curve nor tensiometer curve have been measured:

1- The ShC and the tensiometric curves were measured; two cases:

a. The ideal case: the two curves were measured on a same undisturbed sample (or on two separate repetitions) and all the shrinkage phases are clearly distinguished on the shrinkage curve. The following parameters for the micro pore system (V_N, k_N, W_N), and the interpedal pore system(K_{bs}, k_M, W_M, k_L, W_L), respectively, are determined on the measured ShC. The tensiometric curve will be used for determining E_{ma}, E_{mi}, σ and W_{sat}, the water content at saturation (zero suction) by fitting equations of h_{mi} and h_{ma} (Eqs 8 and 9) on the measured curve, were W_{mi} and W_{ma} are calculated using parameters of the ShC

b. Depending on the soil type or if the measurement was made on reconstituted samples (disturbed structure), only the micro parameters: V_N, k_N, W_N, and K_{bs} can be determined or are valid using the S_hC. The tensiometric curve is used, thus, for getting the rest: W_M, k_M, W_{sat} (may be different from W_L), E_{ma}, E_{mi} and σ.

c. Thus, KamelSoil® has an excel sheet that can treat a set of (W, h) data coming from a tensiometric measurement for determining the macropore system parameters by fitting the two equations of h_{mi} and h_{ma} (Eqs 8 and 9) on the measured curve. An excel sheet also is attributed to the treatment of a set of (W, V) data from the SC measurement.

2- The tensiometric curve was only measured. Three more parameters are required. These parameters can be found in soil database or estimated from texture and organic matter using appropriate pedotransfer functions:

a. The bulk density (DBD (dry) or BD (sat)) corresponding to the specific volume at dry state or moist state: VN or VL. If DBD or BD are given their value are put in the input Data sheet of KamelSoil®; if not, BD moist will be estimated by KamelSoil® using PTFs via θsat (or Wsat) and the density of the solid phase supposed equal to 2.65, according to the following equation:

b. $1/BD = 1/2.65 + Wsat = 1/2.65 + \theta sat /BD$ (14)

c. The standard COLE index for calculating $\Delta V=VL-VN$ then Kbs according PTFs given by Braudeau et al. (2004b)

d. The wilting point W1500 (soil moisture at 1500 kPa) for estimating WN and kN using the tensiometric curve and assuming that this point corresponds to the air entry points WB on the ShC (Fig. 1). In general, this information is measured in kg/kg in soil data bases. If W1500 is a measured data, its gravimetric value kg/kg is put in the Data input sheet of KameSoil®. If not, PTFs (Saxton 1986) will calculate it in m3/m3(in Saxton sheet).

3- The ShC and the tensiometric curve were not measured (or given): thus, in addition to the three characteristics above, the two following characteristics are required such as the soil moisture at 100 kPa (1 bar), W_{100} and at 33 kPa: W_{33}. Like in the previous paragraph, these characteristics are generally measured and found in the soil data bases in kg/kg. If not, they will be estimated in KamelSoil® using PTFs according to Saxton (1986) or Saxton and Rawls (2006).

With W_{1500}, and W_{33}, one can calculate the two parameters A and B of the exponential equation used by Saxton and Rawls (2006) for representing the tension segment of 1500 to 33 kPa:

$$h(1500\text{-}33)= AW^{B} \quad (15)$$

In KamelSoil® we use this segment of curve to fit h_{mi} on these three points (W_{1500}, W_{100} and W_{33}) and to h_{ma} between 60 kPa to saturation. The assumption here is that h_mi and h_{ma} are equal up to saturation, which is the case for many soils. Thus, the segment between 33 and saturation which is taken as a straight line by Saxton and Rawls (2006) is actually modelled by h_{ma} or h_{mi} under this assumption. This modelling provides W_M, k_M, W_{sat}, , E_{ma} , σ, E_{mi}, W_N, and k_N.

II – Estimation of the dynamic parameters

1°) Parameters of the interpedal conductivity (k_{ma})

Parameters of $k_{ma}(W_{ma})$ in equation 12 are estimated by fitting this equation to the conductivity curve $k(\theta)$ simulated by Brooks and Corey equation (1964).

$$k(\theta) = k_{sat}{*}((\theta - \theta r) / (\varphi - \theta r))^{\wedge}n \quad (16)$$

where parameters θr, and n are determined by PTFs from clay%, sand % and porosity (volume fraction) according to these authors. The conductivity at saturation k_{sat} is calculated by the Saxton and Rawls (2006) procedure according equation 16:

$$k_{sat} = 1930(\theta_{sat} – \theta_{33})^{(3 – 1/B)} \quad (17)$$

where B is the parameter of equation 14 calculated with points (1500, W1500) and (33, W33).

The conductivity equation of Kamel® (Eq.13) is then adjusted to the conductivity curve of Brooks and Corey (1964) (Eq. 17) according the meaning of the Kamel® parameters:

$\alpha_M = n/(W_L-W_N)$; $k_{ma°}= k(\theta_C)$; $k_{maM} = k(\theta\ M)$; and α_o given by equations 12 and 15 at $W=W_M$ ($W_{maM} = -Ln(2)/k_M$)

The solver is then used to improve the fit using α_M as the changing parameter to be determined.

2°) The absorption rate of water by the swelling plasma of primary peds, k_{mi} , is scarcely measured. The time of half charge, $t^{1/2}$ depends of the material and its degree of division in the structure. It can be fixed at 30 minute, waiting for more investigation.

Conclusion

The basic principles of Kamel® were presented. They constitute a new paradigm for the soil physical characterization and modelling that take account of the internal soil organization (primary peds, pedostructure, the functional pore systems, water pools etc.) in its interaction with the water. The new concept of Structure Representative Volume (SRV), in addition to the well know REV concept, allows to characterise the soil in laboratory, to model the hydrostructural functioning of the soil at the process level, and to transfer the information to a macroscopic point of view at the field scale into REV variables. For be able to work in any situation more or less rich in measured data, or like any soil water model, KameSoil® was elaborated for translating the generally available soil data into the physically based and independent parameters of Kamel® using the pedotransfer functions published in the literature.

Future work will focus on the development of pedotransfer functions that estimates K_{bs} and K_{mi}. Moreover, the effect of overburden pressure along the soil depth profile on soil structure, water content, and behaviour will be examined. In addition, the effect of soil management practices (cultivation, tillage, irrigation, est.) on soil behaviour will also be addressed in future work.

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Appendix or Nomenclature

The 15 pedohydral parameters needed for modeling the soil-structure and water interaction within the soil medium (parameters of the surface layer are not included). Symbols used: ShC, Shrinkage Curve; TC, Tensiometric Curve, CC, Conductivity Curve; and S_WC, Swelling dynamic Curve.

Parameter	unit	kind	used in	name
V	dm^3/kg_{soil}			Pedostructure specific volume
V^{μ}	dm^3/kg_{soil}			Primary peds specific volume
V_s	dm^3/kg_{soil}			Solids (primary particles) specific volume
Vp	dm^3/kg_{soil}			Pedostructure pore specific volume
Vp^m	dm^3/kg_{soil}			Macropore specific volume of pedostructure
Vp^{μ}	dm^3/kg_{soil}			Micropore specific volume of pedostructure
W	$kg/kg_{dry\ soil}$			Pedostructure water content (soil moisture)
w_{re}	$kg/kg_{dry\ soil}$			Pedostructure residual water pool
w_{bs}	$kg/kg_{dry\ soil}$			Pedostructure basic water pool
w_{st}	$kg/kg_{dry\ soil}$			Pedostructure structural water pool
w_{ip}	$kg/kg_{dry\ soil}$			Pedostructure interpedal water pool
A, B, C, D, E, F				Shrinkage transition points of the SC defined by the XP model
N’, M’, L’				Intersection points of the tangents to the SC at the linear phases
N, M, L				Characteristic points of the SC at the vertical (y-axis) of N’, M’, L’
I_{st}, I_{bs}				Inflection points of structural and basic shrinkage phases
W_A, W_B … W_F				Pedostructure gravimetric water content (kg/kg) at points A, B ... F
V_A, V_B … V_F				Pedostructure specific volume (dm^3/kg) at points A, B ... F
K_{re}, K_{bs}, K_{st}, K_{ip}	kg_{soil}/kg_{water}			Slopes of the SC linear phases (dm^3/kg)
k_N, k_M, k_L				Shape parameters (kg/kg) of the SC equation
V_A	dm^3/kg_{soil}	S_hC	$V(W)$	Pedostructure specific volume at dry state
W_N	kg_{water}/kg_{soil}	S_hC	w_{bs}, Ps_{mi}	Pedostructure gravimetric water content at point N
W_M	kg_{water}/kg_{soil}	S_hC	w_{st}, W_{ma}, h_{ma}	gravimetric water content at point M
W_L	kg_{water}/kg_{soil}	S_hC	‘‘	gravimetric water content at point L (saturation)
k_N	kg_{soil}/kg_{water}	S_hC	w_{re}, w_{bs}	Constant of equilibrium between w_{bs} and w_{re}, during drying
k_M	kg_{soil}/kg_{water}	S_hC	w_{bs},w_{st}, W_D, W_C	Constant of equilibrium between w_{bs} and w_{st}, during drying
K_{bs}	dm^3/kg_{soil}	S_hC	$V(W)$	Scaling ratio between pedostructure and prim. peds
E_{ma}	joules/kg soil	TC	$h_{ma}(W_{ma})$	Potential energy of the external surface of primary peds

σ	kg_{water}/kg_{soil}	TC	h_{ma}	Skin water at the surface of primary peds
$k_{ma^{\circ}}$	dm/s	CC	$k(W_{ma})$	Hydraulic conductivity at dry point of macroporosity
k_{maM}	dm/s	CC	‘’	Hydraulic conductivity at saturation
α_o	kg soil/kg water	CC	‘’	Const. of the exponential increase of k_{ma} with W_{ma} for $W < W_M$
α_M	kg soil/kg water	CC	‘’	Const. of the exponential increase of k_{ma} with W_{ma} near saturation
E_{mi}	joules/kg soil	S_WC	h_{mi}, Pc, Ps_{mi}	Potential energy of the internal surfaces of primary peds
k_{mi}	$kg_{water}/kg_{soil}/kPa/s$	S_WC	V(t), dw_{bs}/dt	Exchange rate coefficient between W_{mi} and W_{ma}