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Simple device, experimental approach and data analysis for evaluating hydration kinetic and water retention of soils

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Abstract

The artificial planting aims at developing non spontaneous flora on handled substrates, as sport areas, dumps, civil engineering earthworks or mine heaps; it also deals with replanting eroded, weathered or aged in bad conditions areas. The main question is to propose an adapted correction to these kinds of soils; in fact, such a correction needs an evaluation of their properties before and after correction. The evaluation of the hydration kinetic and retention capacity needs adapted analytical devices and a long time, incompatible with the allotted answer needs. The hydration of solids concerns different kinds of water, microscopic and macroscopic hydration water with different physical properties, only the last form is available for plants. Here is proposed a simple method to determine the macroscopic water adsorption at equilibrium and the corresponding half-time reaction. The method is based on a second order kinetic model. It has been shown, at pilot scale, on a golf course in Oman that an adapted correction leads to spare 65% of the watering volume and confirms that this type of system reaches the equilibrium only after a close to two months duration. The spared volume can be converted into watering cost, significant differences depend on the local rate of water, the gain involves also the non-exportation of weed killer, pesticides and fertilizers by streaming flow. In addition, the two months delay has an outstanding importance for a credible evaluation procedure.

Keywords: soil, poor agronomical properties, water adsorption, hydration kinetics.

1. Introduction

Soils remediation consists in changing the natural flow of water by draining and watering and in adding substances for correcting some defects, either natural or resulting from diverse exportations (crops, mowing…). The soil is an open chemical reactor; its story and future are then ruled by mass balance principle. However, the physical quality of a soil also depends on the manner in which the particulate components are associated, so-called “structure“. The size distribution and the stability of aggregates control the oxygenation, the water retention, then the microbiological activity and finally, the growth of plants [1, 2]. Three groups of compounds govern the structure: clays, iron and aluminium hydroxides and organic matter [3, 4].

The structure of a soil results from the different events it underwent. For example, the hardening of unsaturated clayed soils by packing is due to drying forces that make the particles closer each-others, but it is increased and made non reversible by applying mechanical stress, for example resulting from the rolling of agricultural machines. The critical point is the early stage of drying [5]. In the same way, some climatic events and some agricultural practices [6, 7], leading temporarily either to an exhausting of the hydric reserves or to an excessive moisture, damage the physical stability, and then, a good biological behaviour of soils.

The artificial planting aims at developing non spontaneous flora on handled substrates with poor agronomical properties, as sport areas, dumps, civil engineering earthworks or mine heaps; it also deals with replanting eroded, weathered or aged in bad conditions areas, for example rice fields that would have been submerged by sea water for a too long time. The fertilisation involving only organic compounds is often inefficient, since used alone and incorporated separately, the organic colloids cannot bring to soils the same structures as they do when associated with minerals. The fine grained minerals are possible carriers for almost all the chemical elements and many organic functions at least for a given duration. Crops and meadows export some elements, leading to dysfunctions, the poorer the soil, the more drastic they are. In addition, some crude organic matters spread in poor acid soils let, after degradation, a hydrophobic skeleton that also generates pathologies.

To manage these situations, some minerals with controlled properties, must be incorporated in the soils. Such a blending needs the analysis of the initial state, the design of the correcting agent, the research of convenient sources of minerals and, finally, the economic validation of the operation. Such additions can be carried out either on the formulation stage of artificial substrates or, when correcting pathologies. For cost reasons, residual minerals are preferred [8]. Though these aspects generated a considerable volume of academic works and results, they are weakly applied by professionals.

2. Theoretical background

The surface hydration of mineral colloids to low relative equilibrium pressure obeys a first order homogeneous kinetic. This hydration is very fast (equilibrium reached after 20 mn) and its analysis allows the determination of activation energies for the different solvation shells of compensating cations [9].

To the contrary, the so-called “macroscopic hydration” to higher equilibrium pressure, is slower (around two month) and, for reasons that would have to be determined, obeys a second order homogeneous kinetic. The mechanism was studied in very rigorous analytical conditions, notably using oedometry measuring the deformation (swelling) and operating in isothermal conditions [10, 11].

Hydrating a divided solid, a deformation ε is observed at time t and after a given time, this deformation stabilizes at a value ε_f.

The progressing degree of the deformation is defined as

$$\alpha = \varepsilon/\varepsilon_f \qquad (1)$$

By definition, the reaction speed v is the ratio between the progressing degree ($d\alpha$) and the time increment (dt): $v = d\alpha/dt$

The second order homogeneous kinetic model can be written as:

$$d\alpha/dt = k\,(1 - \alpha)^2 \qquad (2)$$

where “k“ is the Arrhenius’ constant.

Resolving equation (2) leads to the following solution:

$$1/(1 - \alpha) = kt + C \text{ where C is an integrating constant} \qquad (3)$$

Considering that to the origin of time ($t = 0$), the progressing degree is equal to 0, ($\alpha = 0$), the relation (3) becomes:

$$\alpha/(1 - \alpha) = kt \qquad (4)$$

Defining t_{50} as the half deformation time ($\alpha = 1/2$), relation (4) becomes:

$$\alpha/(1 - \alpha) = t/t_{50} \qquad (5)$$

combining relations (1) and (5) leads to:

$$\varepsilon/(\varepsilon_f - \varepsilon) = t/t_{50} \qquad (6)$$

that admits the following linear expression:

$$t/\varepsilon = t/\varepsilon_f + t_{50}/\varepsilon_f \qquad (7)$$

Then plotting t/ε as a function of t gives a straight line of slope $1/\varepsilon_f$ and ordinate to the origin t_{50}/ε_f. This representation offers then the possible determination of t_{50} and ε_f, it closely fits the experimental data with a linearity respected on the whole time scale (figure 1).

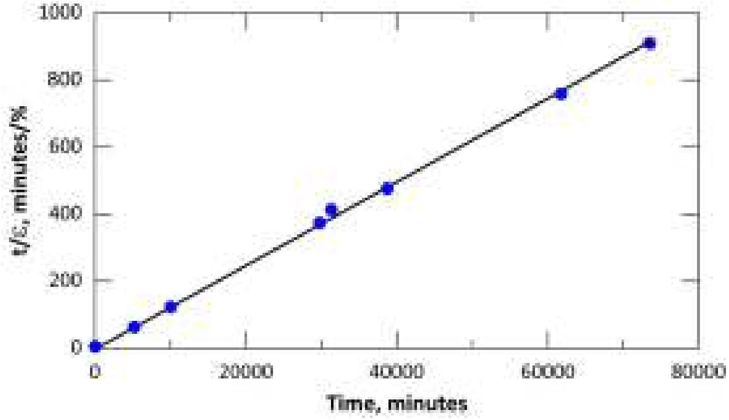

Figure 1. Linear representation of the hydration of a random beidellite-kaolinite interlayer, according to a second order dynamic model (adapted from [11]).

Different possibilities are offered for taking advantages of this relation. A graphical resolution is possible. One can also use two chosen points of the straight line [1 (ε_1, t_1) and 2 (ε_2, t_2)], what allows to calculate ε_f and t_{50} according to the following relations:

$$\varepsilon_f = \varepsilon_1\ \varepsilon_2[t_1-t_2/(\varepsilon_2 t_1-\varepsilon_1 t_2)] \tag{8}$$

and

$$t_{50} = t_1[(\varepsilon_1 t_2-\varepsilon_2 t_1)/(\varepsilon_2 t_1-\varepsilon_1 t_2)] \tag{9}$$

It is also possible to use a linear regression; this resolution is preferred since it brings the best statistical quality of the resolution.

3. Material and Methods

The upper proposed approach needs to handle delicate devices and an experimental care. These conditions are usually incompatible with the knowledge of horticulture workers and their answer delay. Then we propose a simpler and faster answer, though reliable, in spite of risks of analytical errors. The main interest of the method is its possible management by poorly experienced operators.

A mass “m” of sample is placed in an aluminium nacelle just when extracted from a regulated at 105°C stove. This sample in its nacelle is placed in a case with deionised water in its bottom (figure 2). A small aperture allows the pressure equilibrium with the atmosphere. After a given time “t”, the nacelle with the sample is weighted; the weight of the whole is “p“. The water adsorption is evaluated by the mass gain and given here as grams for one hundred grams of dried mater. For comparisons, a crude substrate and the same corrected substrate are analysed in contiguous cases (figure 2).

Figure 2. Devices for kinetic analysis of adsorption. On each side, are presented the equilibrium cases; down; the empty nacelles; in the middle, the filled nacelles on their supports.

The adsorbed quantity at time t is

$$q = (p-m)/m \tag{10}$$

and this quantity stabilises at a value “q_f“.

By analogy with relation (7), the homogeneous second order kinetic can be linearized under the form

$$t/q = t/q_f + t_{50}/q_f \tag{11}$$

where q and q_f respectively are the adsorbed quantities at time t, and the adsorbed quantity at equilibrium. Simply, deformations have been replaced by mass growths. Such a representation suggests a linear distribution with a slope $1/q_f$ and an ordinate to origin t_{50}/q_f.

The main analytic risk of this device is due to possible variations of temperature that may generate variations of the saturating pressure of water. The trials mentioned here after have been carried on between 16 and 18°C, then with variations of the saturating pressure between 1.819 and 2.065 mega-pascals [12]. In our semi-equilibrium conditions, the corresponding variation of the adsorbed quantities are significant only close to the saturation, between 0.98 and 1 [13], then at the end of the kinetic curves.

Substrates were collected on the sight of Oman golf course and constituted as an average sample. They were analysed by X-ray diffraction and infrared spectroscopy. The mineralogical composition is very close from one sample to another. The major minerals are quartz, calcite, dolomite and plagioclases feldspars, the minor minerals are vermiculite, chrysotile and other antigorites, micas (illite) and amphiboles of actinolite-tremolite series. These compounds are free of functionalized organic carbons. This soil with very poor hydric reserves has then been modified by addition of a corrector for overcoming these defects. The weight composition of the corrector is as follows: one part in weight of swelling sheet-silicate, one part of sheet-silicate with large external surface and one part of mature organic carbon. 3% of this corrector is mixed with the substrate (4.5 kg /m^2 on 10 cm depth).

4. Results and Disscussion

The crude data on adsorption (figure 3) show many points. The first one is that the soil reaches its mechanical equilibrium only after two months, what suggest to conclude about the replanting trials only after this delay. The second point is that the four last measurements on the crude substrate have been done after an accidental drying of the water reserve, that generated a desorption. This last fact points out a possible critical analysis of the results.

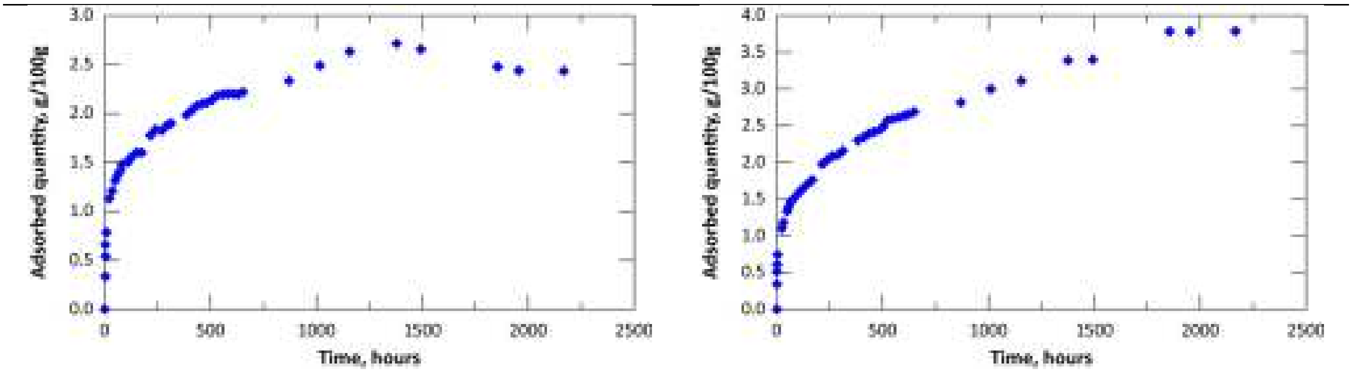

Figure 3. Crude adsorption data, on the left, crude substrate, on the right, corrected substrate.

The linear modelling according to a second order kinetic is given in figure 4.
According to relation (11), the linear regression allows to deduce the hydration at equilibrium and the half reaction time. For the crude substrate, the equilibrium hydration is 2.31 g/100g and the half-time reaction 64.3 hours. For the corrected substrate, the equilibrium hydration is 3.83g/100g and the half-time reaction 178 hours.

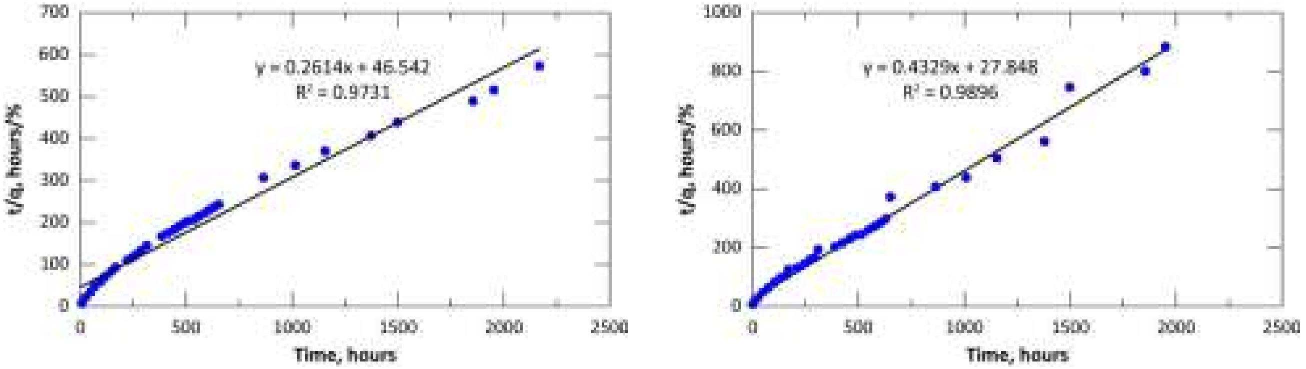

Figure 4. Linear modelling according to a second order kinetic (relation 11). On the left crude substrate, on the right, corrected substrate.

Therefore the proposed amendment increases the water retention capacity and slows down the kinetics. In other words, on the crude soil, the water retention at equilibrium is 16.2kg/m^2 on a 50 cm depth and the vegetables cannot take advantage of it since it is transferred to the aquifer or streams off. After correction the water retention at equilibrium is 26.8kg/m^2 on a 50 cm depth. This calculation proposed for an arbitrary depth of 50 cm, must be adapted to the depth explored by the roots according to the type of planted vegetables. Anyway, the proposed amendment increases the retention of 65%.

5. Conclusions

According to the experimental results, the kinetics of the so-called “macroscopic hydration“ is very slow (around two months to reach equilibrium); this point suggests a thought about the time interpretation of amending results.
Modelling according to a second order kinetic allows evaluating the hydration capacity and the half-time reaction. The main interest of such a model is to evaluate these parameters a long time before equilibrium, thus saving time for the characterisation.
A proposed amendment increases the water retention capacity and slows down the hydration kinetic. The increase of the retention capacity suggests adjustments of the watering procedure. It is useless to water the soil more than its retention capacity since the water excess is wasted by diverse ways and cannot be used by plants. In addition, these results also suggest that a system for water recycling is relevant mainly for ruling

the watering volumes, lysimeters would allow to appreciate the nominal watering volumes and their frequencies.

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